WORKS LIGHTING

D. H. OGLEY, B.Sc.

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WORKS LIGHTING.

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BY

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AUTHOR'S NOTE.

FROM the point of view of lighting progress, one of the most important events of recent years was the appointment of a Government Committee to enquire into the whole subject of industrial lighting.

The Committee have placed it on record that, in the course of their visits to various parts of the country, they were much struck by the unanimity of opinion among manufacturers as to the utility of these investigations, there being a general conviction that an enquiry which may suggest means of reducing the wastage in human life and labour is of national importance, and ought to be encouraged.

The recommendations of the Committee are of vital importance, since there is no longer any doubt that the degree of comfort in the working conditions is largely determined by the adequacy of the lighting. Manufacturers, without exception, cannot but agree with the suggestion that there should be a statutory provision

(*a*) Requiring adequate and suitable lighting in general terms in every part of a factory or workshop ; and

(*b*) Giving power to the Secretary of State to make orders defining adequate and suitable illumination for factories and workshops, or for any parts thereof, or for any processes carried on therein.

With a view to assisting the manufacturer in arriving at a decision as to what is adequate illumination for any purpose, this work has been compiled. All practical lighting systems have been considered, and the special sections are as far as possible complete in themselves. It is hoped that this feature will be appreciated by those interested in the various illuminants.

At the same time, the need for co-operation in the lighting industry is fully recognised, and an impartial treatment of the subject has therefore been provided with a view to benefiting all systems of lighting, and encouraging the engineer to keep in touch with the latest developments in illumination.

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PREFACE.

IT is becoming recognised with increasing clearness that the physical surroundings and conditions of the industrial worker exercise a most important influence, both in the amount and quality of the product of a factory.

This book, therefore, is both opportune and useful, for of all physical conditions, lighting is probably more important than any other in promoting efficiency and cheerfulness.

The author, Mr. D. H. Ogley, B.Eng., has quoted some interesting statistics prepared in the United States as the result of an investigation of over two hundred factories, employing 80,000 workpeople, in which it was shown that the percentage of spoilage under artificial light was three times as great as it was under natural illumination. Not only, therefore, is efficient lighting a good thing in itself, *but it pays* as a purely commercial proposition.

As is said by *The Automobile Engineer,* in the article which introduces to its readers the articles on which this book is based, "It is an amazing thing that, whereas any amount of abstract scientific research and practical skill and care are devoted to extracting the highest degree of efficiency from a tool or a piece of metal, yet the manufacturer will use his most delicate, complex, and variable tool, namely, the worker, with the most complete disregard for the condition or fitness for the work of this particular unit."

That there is need for a reorganisation of many factories in respect to lighting is evident from some figures quoted by Mr. Thorp, who states that in a certain factory the average daylight illumination was 32 foot-candles, with a minimum of 8.6 foot-candles, whereas with flat flame gas burners (which are still in use to a surprising extent) the illumination was only 0.6 foot-candles.

The eye is one of the most wonderfully adaptable of living organisms. It can adjust itself, when necessary, without injury, to illuminations varying between very wide limits ; but it is a very severe test for any organism to adjust itself for regular work to conditions which vary between limits of nearly fifty to one.

Not only is it necessary that good artificial light should be employed, but attention should also be given to natural lighting.

The subject of lighting and window space has been studied for a long time in connection with the lighting of weaving sheds and other factories where the need of good illumination has been evident from the nature of the work to be performed ; but good lighting has an effect on the worker himself. Men and women working in well lighted, well ventilated rooms, which are kept at an equable temperature, summer and winter, will produce a much greater output of work than others less favourably placed. How great this influence is has not been fully realised. Mr. Ogley quotes the case of a munition factory in which the output of a night shift was increased by over 30% by the introduction of an efficient system of lighting.

The science of illumination (for which the Illuminating Engineering Society has done so much in this country) has come to stay. It will, as the years pass, come to be recognised as one of the most important of the applied sciences, and one which will involve a large amount of physical, engineering, and physiological research before it can be regarded as completely understood. Like every other science, the more it is studied the more subjects of study in connection with it arise.

So far, most tests have been made on the quantity of light per unit area which is available ; undoubtedly the colour of the light has also to be considered.

The eye has adapted itself to the radiation from the sun, which is of the greatest intensity, and it may well be that light spectra different from that given by the sun will produce more eyestrain and fatigue than illumination approximating more closely to natural daylight. Another most important factor in eyestrain is glare. The shading of lights, therefore, is a subject of the very first importance.

A book such as this, which deals with all kinds of illuminants, their efficiency as light producers, the shading of lights, and their application to the conditions of the modern workshop, should be of the greatest value to all manufacturers and works engineers. It forms part of a propaganda which it is hoped will be continued with increasing activity to improve the conditions of our workshops and the physical condition of our workers, and, from the purely humanitarian standpoint, deserves the careful consideration of those who (whether they recognise the fact or not) are largely responsible for the physical welfare and happiness of a large number of their fellow countrymen.

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CHAPTER I.

GOOD LIGHTING AS A FACTOR IN EFFICIENT WORKS ADMINISTRATION.

THE problem of efficient works administration is inherently complex, and one of the most difficult elements entering into the problem is unquestionably that of the conditions under which the work is performed. This point was emphasised some short time ago by the president of the Westinghouse Manufacturing Co. during an informal address to his foremen and other employees, when, with reference to general phases of the work in progress, he stated that "this is a difficult problem which we are all trying gradually to solve."

There are undoubtedly many manufacturers, works managers, and others who fail to realise the true significance of this remark in connection with industrial work.

The processes of manufacture, the environment under which the work is carried out, and the relations existing between employer and employee, may all seem to be items which are clearly defined, and it is the failure to realise the number and diversity of the factors entering into the problem of efficient control which causes wonder and dismay when a strike or other stoppage indicates the lack of agreement so essential to industrial progress.

The subject of factory conditions has been surveyed in a very practical manner by the committee appointed by the Ministry of Munitions on the health of munition workers. Many of the problems which arose for consideration were found to involve the conditions determining industrial fatigue, and to be closely related to lighting problems, a study of industrial hygiene in its broader aspects being in fact of considerable assistance to those engaged in the problem of industrial lighting.

IMPORTANT FACTORS IN ENVIRONMENT.

An enumeration of the primary requirements of a factory may seem unnecessary, but a closer acquaintance with the average factory brings home the need for insisting upon the observance of fixed rules with regard to such items as ventilation and lighting.

In all buildings, for example, it is important to maintain a suitable working temperature throughout the year. The operatives should never be subjected to the extremes of heat or cold, and yet in quite recent times we hear of factories closing down for no other reason than that work was impossible owing to the lack of heat. Adequate ventilation and a sufficient illumination by day and night should also be insisted upon, while such items as cleanliness, the supply of water and dining facilities, may be added to the list of primary requirements.

The actual working conditions should, as far as possible, conform with those ruling in the home. Life, whether in the home or factory, demands for its welfare a definite kind of environment if its forces are to be conserved. In this respect one set of home conditions and another in the factory handicap the workman, and make his efforts to keep himself in health more difficult than those of another workman who labours amidst more satisfactory surroundings.

Quite small plants have developed at an alarming rate, vast numbers of new factories have been erected, and additions have been made to almost every existing controlled establishment. It is natural, perhaps, under the circumstances that the interests of the workpeople should have been overlooked. In many cases practically no provision exists for adequately lighting or heating the extensions, while in a large number of the new factories the lighting arrangements are of the most primitive nature imaginable.

THE IMPORTANCE OF GOOD LIGHTING.

The management of a factory invariably strives for an increased output at a decreased cost, with an improvement in the quality of the article manufactured whenever possible, and concerned in the realisation of these aims are the three items of labour, machinery, and lighting.

The importance of these items may be more fully appreciated if it is understood that any two of them may be rendered useless by the absence of the third.

Poor tools have a direct adverse bearing on the quantity and quality of the work turned out, and just as a factory must keep abreast of the times by the installation of the most efficient and up-to-date automatic labour saving machinery, so it is economy in the strictest sense of the word to install only the most adequate lighting arrangements it is possible to obtain.

In the words of the Home Office Departmental Committee on Lighting in Factories, "there is a general consensus of opinion as to the economic and hygienic advantages of adequate and suitable lighting."

Light is indeed the most important tool placed at the disposal of the workman, for without light all other tools are useless. The good lighting of a factory is one of its most valuable assets, and the pressing need of statutory requirements relating to the lighting of factories, etc., and similar to those already existing in connection with heating and ventilation, has recently been emphasised very strongly by the work of the above committee.

The enquiry showed that, although there has been a great advance made in methods of illumination, many defects are still to be met with. Complaints of eye-strain and headaches were frequently received during the investigations, and the reports of the expert witnesses showed that, while medical evidence would be necessary before a definite statement could be issued, a general impression was abroad that unsatisfactory lighting was prejudicial to health.

There is no questioning the fact that good work can only be obtained with the workpeople under reasonably comfortable conditions, and good lighting is one of the most essential of these if the well-being of the employees is to be considered.

Freedom from eye-strain, with ability to distinguish detail, is the only condition under which workpeople should be allowed to carry out their various operations, and the neglect of employers to provide those dependent upon them with an adequate and correct illumination is the more surprising, in that investigation shows that the average factory pays more for bad lighting than would be the case if the installation had been correctly designed.

The money value of good illumination is a point which cannot be too strongly emphasised, for the employer naturally considers the financial aspect when the question of a revised lighting scheme is broached.

Apart from the saving to be effected in actual running costs, as previously instanced, there is the much more important point of decreased spoilage to be considered. The scrap bill is almost invariably much greater during periods of artificial illumination, and the increase is to be traced to the neglect of the management to provide a sufficiency of correctly directed light. The quality of the work must suffer if the workman is unable to carry on the necessary operations with the maximum of efficiency, and absence of light will render nugatory the best of efforts and intentions.

An indifferently lighted shop—and the author can speak from experience of many—always has a depressing effect upon the spirits. This is an important point, and if the employer could only be made to realise the truth of this assertion wonder would no longer be expressed at the frequent complaints of slackness during periods of overtime and night work. The workpeople are merely unhappy in their surroundings, and while in this condition they obviously cannot take any special interest in the work they have in hand. To keep workpeople active and wide awake it is necessary to make them feel wide awake, while to keep them cheerful and, incidentally, in better health, a cheerful atmosphere is necessary. A well-lighted shop serves both purposes, for not only does it keep the men wide awake, but it also conduces to a feeling of cheerfulness, and both these factors—taken in conjunction with the ability of the men to see round their work and to distinguish detail—will show immediate results in an increased output and a decreased spoilage. Further, the employer has the satisfaction of knowing that the sight of his workpeople is being conserved, and, in view of the recent reports from eye hospitals, this is a point upon which too much stress cannot be laid.

STATISTICS FROM THE U.S.

With the purpose of ascertaining how far the arguments in favour of good lighting are supported by practical results, an extensive enquiry was made a year or two ago throughout a large number of factories in the United States. Reports were received from 209 establishments, of which number 164 had recently installed the latest and most scientific lighting appliances.

The results directly attributed to the improved lighting are of great interest. In no fewer than 157 cases the investment was considered to have justified itself for at least two good business reasons.

The employees in some sixty of the factories were said to be more contented. Special stress was laid on this point in many cases, it being freely stated that the good lighting ensured fewer complaints, an increased output, decreased spoilage, and less illness and fatigue amongst the hands.

Statistics on the subject are in close agreement with the views expressed.

Experts agree that the average gross spoilage in the total manufactures in the States is at least 1%, and of this amount 75% is estimated to occur under artificial light. Scientific lighting, it is held, could reduce the loss by at least 25%, resulting in an annual saving of well over two million pounds.

Reduced Cost of Production.

On the important point of reduced cost of production, over thirty manufacturers reported that the improvement in the lighting had resulted in an increased production, while sixty stated that not only had the quality of the output improved, but that the percentage of seconds had also decreased.

Lost time accounts for much in factory output, and the manager of a large silk mill estimated that with a hundred looms running the time lost through indifferent lighting meant that two or three looms were worn out each year without the production of a single yard of cloth. In addition, the power to drive the machines had also to be considered.

Good lighting pays, no matter from what angle the subject is viewed, and a close enquiry will reveal the fact that the cost of lighting is one of the smallest items in the factory charges.

Saving on lighting is false economy, the policy, if pursued, sacrificing many times over any apparent gain.

Good Lighting and Safety.

An exhaustive enquiry by the Lighting Committee into all reported accidents during 1913 and parts of 1914 would make it appear that in respect of accidents due to " persons falling "—a cause that would seem to be specially dependent on lighting conditions—the percentage of total accidents is higher during the period of the year when artificial lighting is used than in the summer months. Further, it has been possible to calculate the probable accident rate per hour separately for artificial and natural lighting, the results indicating that for most industries the former is far higher than the latter, in some cases to the extent of 40%. It has also been placed on record that the number of accidents occurring in shipbuilding yards at night is quite out of proportion to the small number of men employed, while reports of accidents caused by indifferent lighting in such places as foundries, iron and steel works, and mills are common.

From the book "Prevention of Industrial Accidents" the following is abstracted: "Statistics show that the greatest number of accidents occur during the months of diminishing light." This can only mean that the percentage of accidents increases during the months of increased artificial light, and this again points to the fact that poor lighting is responsible for the increase. The Manufacturers' Association further remarks that in the United States alone over half a million avoidable accidents have occurred in one year, and it is claimed that 25% of these accidents were caused by the poor lighting of the places concerned. Good lighting is thus essential in the interests of the safety of the workpeople, and should be demanded as part of the safety outfit of the factory.

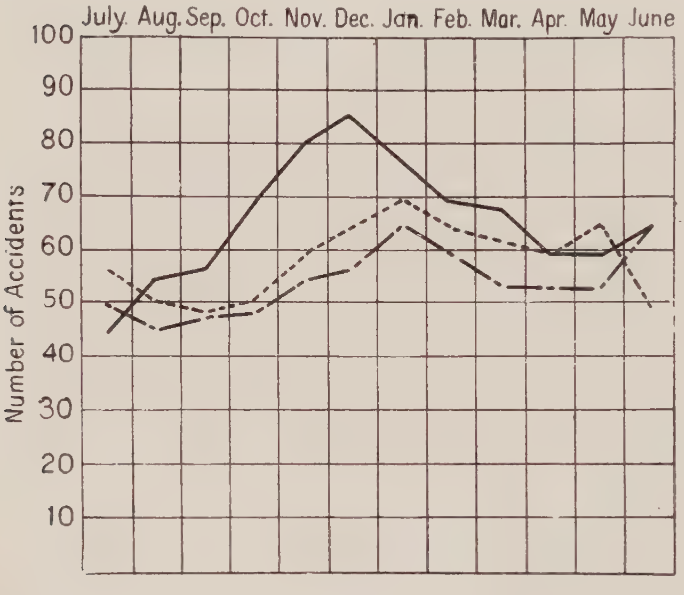


FIG. 1.—Monthly distribution of accidents over three successive years reported from an area embracing 80,000 factories.

In this connection the chart shown in fig. 1 is of great interest, indicating, as it does, the number of accidents occurring during three successive years from a district embracing 80,000 plants. It will be noticed that the maximum number of deaths always occurred during the dark months, the December returns in one case being almost double those of July of the same year. The only variant being the lighting, the effect of the indifferent nature of the latter is at once made evident, and it is obviously to everyone's interest to secure the best possible lighting arrangements for each given set of conditions.

Fig. 2 indicates the average hours per day of sunshine, cloudiness, and darkness, and, taken in conjunction with fig. 1, the reason for the increase in the number of fatal accidents during the months of October to February should not be far to seek.

OTHER SAFETY CONSIDERATIONS.

The damage to eyesight and the prejudicial effects of bad lighting on the health of workpeople have already been alluded to. Many other aspects of the problem present themselves for consideration, however.

Special efforts were made by the Lighting Committee to obtain clear evidence of cases of direct injury to the eyes through indifferent lighting conditions. It is well known that serious injury may accrue from exposure to very intense light, and many general expressions of opinion were given that insufficient light and excess of light, especially when accompanied by glaring sources of light in the field of vision, are responsible for injury to the eyes.

Inadequate and excessive luminosity of the field of view are both equally undesirable. In the former case the retinal images are not distinct, and the eye grows fatigued in its effort to sharpen their perception.

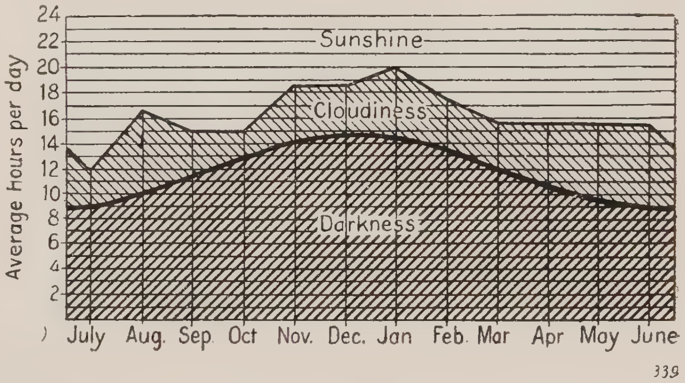


FIG. 2.—Natural light values in New York City.

Excessive brightness produces images which are abnormally intense, causing injury to the retina. The iris contracts in its effort to protect the eye, thus reducing the amount of light entering the eye and rendering the dimmer objects of the field of view indistinct, even though sufficiently bright for normal requirements.

Exposed light sources of great intrinsic brilliancy constitute a prolific source of eye trouble, when placed directly in the field of view, and on this account the eyes of workers should never be exposed to the entrance of direct light from unscreened sources.

The normal eye can regard with equanimity a source whose intrinsic brilliancy does not exceed, say, five candle-power per square inch. An ordinary candle placed within the line of vision will produce no harmful effect.

It will therefore be obvious that the effects on the eye nerves of light sources of high intrinsic brilliancy must be disastrous. Yet in the majority of factories unshaded lamps abound, and the management should be made clearly to understand that such practice is against the workers', and incidentally their own, interests.

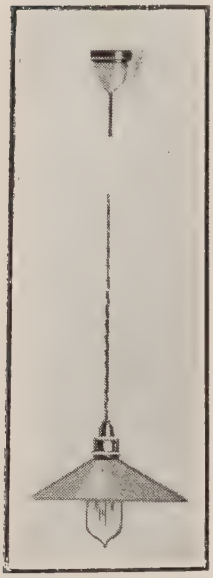


FIG. 3.—The out-of-date drop pendant.

Such antiquated units as the drop pendant (fig. 3) and the fish-tail burner must be eliminated, and their place taken by modern scientifically designed equipment (fig. 4) if good lighting results are to be secured.

UNSATISFACTORY ARTIFICIAL LIGHTING.

The Lighting Committee have classified the chief causes of unsatisfactory illumination under the following headings:

(1.) The provision of too few or too weak light sources.
(2.) Antiquated methods of lighting.
(3.) Inadequate supply.
(4.) Neglect of upkeep.
(5.) Inside obstruction.
(6.) Shadows and placing of lights.

In the general lighting of large engineering works and foundries and in gangways and passages, the illumination is in many cases insufficient. The defect may be overcome by the addition of other light sources or by the substitution of sources of higher candle-power for those already existing. It would be better, however, to redesign the installation, and thus to ensure an adequate illumination at all parts of the working area.

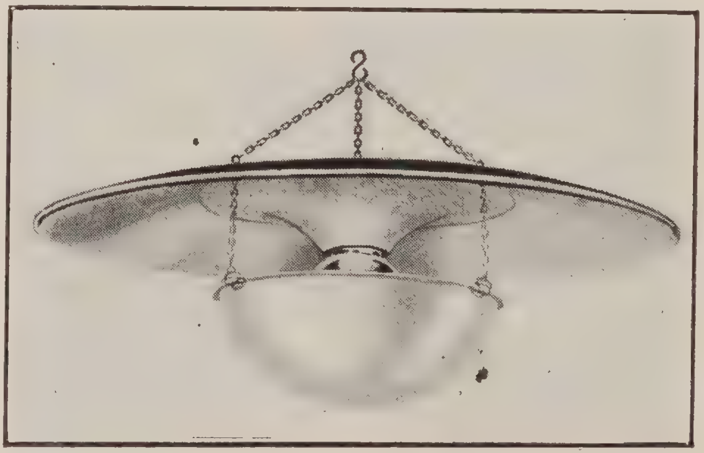


FIG. 4.—Latest pattern semi-indirect lighting unit. Wardle Engineering Company.

Under heading (2) the use of local lighting units, such as gas jets, is deplored. The jets would appear to find favour by reason of their comparatively robust construction, but otherwise they are objectionable in many ways. In addition to flickering and vitiating the air, they are so uneconomical that the small capital outlay required to replace them by a modern system is rapidly repaid by the greater efficiency and diminution in the running expenses.

Inadequate supply deals with diminished gas pressure during periods of maximum demand and with the fall in pressure due to the installation of electrical plant of insufficient size. The remedy lies in making provision for the future when any alteration or the installation of new plant is contemplated.

NEGLECT OF UPKEEP AND ITS RESULTS.

Fig. 5 indicates in a graphic manner the result of dust collecting on reflectors and lamps, and in any lighting system a considerable loss will result from deterioration of the source itself as well as from the deposition of dust and dirt.

In the figure the decrease in illumination is shown after varying periods of time without cleaning, the conditions being such as are met with in the average commercial undertaking.

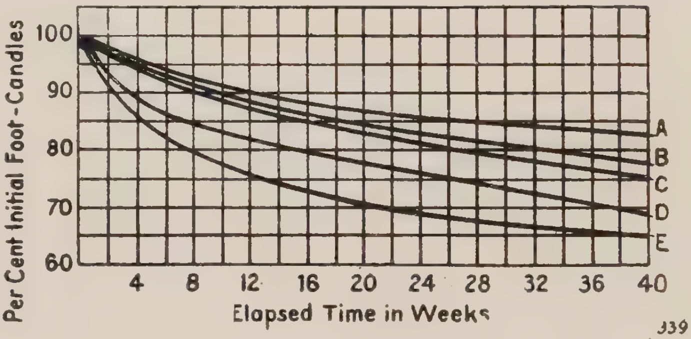


FIG. 5.—Decrease in illumination due to collection of dirt on lamps and reflectors.

A. Shallow dome porcelain enamelled steel reflectors.
B. Deep bowl porcelain enamelled steel reflectors.
C. Dense opal glass reflectors.
D. Prismatic glass reflectors.
E. Light density opal glass reflectors.

The figures exhibited have reference to electrical installations only, but in the case of gas and other sources still greater deterioration is to be looked for.

The tests bring out two important considerations :

(I.) A regular system of cleaning should be adopted for every building or room of any size, regardless of the type of installation or the reflector equipment. In addition, the cleaning should take place at regular intervals of one, two, three, or more weeks, depending upon the amount of dirt in the atmosphere and the degree of cleanliness which the calculations indicate as the most economical to maintain.

(2.) In designing lighting systems it is advisable to allow a certain factor to compensate for the depreciation which will inevitably occur. The actual factor will vary with the conditions, and is largely a question of experience. In electrical installations, for example, where rigid cleaning is insisted upon and good maintenance observed, 10% is a safe figure, but, on the other hand, if the maintenance is poor, 25% is by no means an excessive allowance.

In other words, the necessary intensity should be increased by this amount, in which case the initial illumination will exceed the average selected as desirable in practice.

Cleaning Reflectors and Lamps.

Contrary to the generally accepted ideas, good maintenance is a simple matter, as, apart from deterioration in the filaments and mantles themselves, the decrease in efficiency is due to the dust and dirt which collect on the lamp and equipment.

If, therefore, the reflector is carefully cleaned, and the lamp, in the case of an electrical supply, wiped with a damp cloth, the improvement will be at once apparent. Prismatic reflectors may readily be cleaned by brushing in the direction of the prisms with a stiff brush, although it is better to remove the reflectors and wash them thoroughly in some good cleaning solution.

Soap and water are good, but one of the best solutions for glass reflectors is made by mixing one ounce of nitric acid in one gallon of water. The solution acts quickly and effectively, and if prismatic reflectors are dipped in it they instantly regain the sparkle which they possessed when fresh from the mould.

Loss due to dirt collection is a real money loss, and its cash value may easily be determined. In order that a certain manufacturing process may be economically carried out, for example, a particular intensity of illumination is required. If the intensity decreases it must be obvious that the work will not be as well done as formerly. This clearly points to a direct loss in output, since either the spoilage must increase or the quality of the work deteriorate. On the other hand, if dirt collection, and the consequent light depreciation, do not interfere with the output, then too much light is provided when the installation is clean. The power of the lamps may therefore be reduced and the installation maintained at full efficiency by instituting a regular system of maintenance.

As an example of the saving to be effected, let us assume that an installation comprises ten 500 watt lamps, and that the hours of burning are forty-two per week. Further, let the cost of energy be 2½d. per unit, and the depreciation based on the curves shown in fig. 5.

First assume that the equipment is cleaned when the lamps are renewed, say every 1,000 hours, and that prismatic glass reflectors are employed.

From fig. 5 the depreciation in twenty-four weeks is 24%, and, assuming that the average loss is one-half of this, we arrive at the figure of 12% as the average loss over the whole twenty-four weeks.

The cost of current during this time is approximately £52, from which it follows that the loss entailed must equal £6 5s.

Secondly, assume that cleaning takes place every two weeks. The average loss during this period is 3.5%, representing a loss over the twenty-four weeks of £1 16s.

A clear gain of £6 5s. — £1 16s. = £4 9s. is thus made. Against this gain must be set the cost of cleaning, which, from experience, will not exceed a few shillings—say eight shillings at the outside.

The saving effected by regular cleaning is thus actually ten times the cost entailed, the benefits resulting from the improved conditions being neglected entirely.

DEPRECIATION IN THE CASE OF NATURAL LIGHTING.

Indifferent natural lighting is in many cases simply due to the collection of dirt on the windows and skylights. It cannot be too strongly emphasised that dirt is one of the greatest enemies of efficiency in any lighting scheme. Windows must be kept clean if good results are to be obtained, and a regular system of cleaning should be instituted by every firm. In many cases, also, poor shop management is responsible for obstructions being reared, both inside and outside the factory, in the direct line of the windows.

All storing should be so arranged that interference with the natural lighting is impossible.

In addition, it would be well if the ceilings and walls were kept clean and white for preference. Whitewashing at stated intervals is of great assistance, since the walls, etc., then act as a large light-diffusing surface.

The Lighting Committee state in their report: "Dirty walls and ceilings are frequently noticeable in foundries and other factories where the nature of the work involves the production of smoke or dust. Owing to the decrease in reflecting power, light is needlessly lost, and this effect is specially marked in factories lighted from a saw-tooth roof, where much of the light entering the windows is reflected from the sloping ceiling down on to the work.

"The effect of light-coloured walls and white ceilings on the general brightness of a room, and in affording an effective background to dark objects, is often overlooked, and we desire therefore to direct special attention to this means of increasing the illumination in workrooms at a minimum of expense."

Further points arising out of the natural lighting of factories will be dealt with in a later chapter.

Shadows and Placing of Lights.

The remaining factor concerned in the production of unsatisfactory artificial lighting is the formation of shadows caused by inconvenient location of the light units.

Lamps are frequently so placed that shadows are inevitably thrown on to the work. The shadows may be caused by the worker himself or by some part of the machine, and, since their formation indicates loss of light and an interference with vision, shadows must be avoided by a correct disposition of the luminous bodies.

Reflecting equipment is now available for the production of all possible lighting effects, and a judicious choice of materials will ensure the correct lighting of any room and the maximum output under any manufacturing process.

NATIONAL INSTITUTE OF INDUSTRIAL PSYCHOLOGY.

CHAPTER II.

CHARACTERISTICS OF GOOD LIGHTING.

BEFORE considering the actual planning of lighting installations, it would be well to discuss briefly the question of what constitutes good lighting and the characteristics which distinguish the same from an indifferent display. Some few of the characteristics are self-evident. There must always be a sufficiency of light, or the intensity in foot-candles on the working plane, for example, must be such that the operations can be conducted with ease, comfort, and safety. Sufficiency of light will also ensure the maximum output and the maintenance of quality, while the elimination of conditions prejudicial to the health and safety of the workers tends to a better agreement between employer and employee and the furthering of industrial progress.

From the point of view of sufficiency of light, the following intensities may be recommended as suitable for industrial purposes.

INTENSITIES RECOMMENDED FOR INDUSTRIAL SERVICE.

The unit employed in all illumination measurements is the foot-candle, and is defined as the illumination received by a surface everywhere one foot distance from a source of one candle-power. A fair idea of this unit may be obtained by holding the page of a book one foot away from an ordinary candle and in such a position that the light rays are at right angles to the page of the book. Such an illumination is sufficient for reading purposes, but authorities are generally agreed that a higher intensity is necessary for prolonged and close work.

The range of intensities recommended for industrial lighting and given in Table I. is a fairly wide one, but is necessary on account of the varying conditions to be met with in factory service. Attention must be paid to the class of work, and if this is such as to make an abnormal demand upon the eyes of the workpeople, the higher values should be taken. On the other hand, if ordinary work only is to be considered, an intermediate value should be chosen, while for quite coarse work, making but little demand on the eyes, the lower value will suffice. For working on dark objects, for example, a higher illumination is necessary than for carrying out similar operations on lighter materials, while for small intricate work the higher value would be chosen, the assembly of larger units making necessary an intermediate illumination only.

Then, again, the colour of the light should be such as to be agreeable and non-injurious to the eye. The spectrum of the luminous body should resemble that of daylight as closely as possible, and, since hygienic considerations require an avoidance of light containing an excess of ultra-violet rays, such lamps as the mercury vapour lamps, though useful in many ways, are unsuitable for average installations.

It is frequently necessary, in this connection, to consider the colour value of the luminant employed from the point of view of judging fabrics in their true colours. The light should be such that coloured cloths, etc., appear much the same by daylight as by artificial light. No colour should be unduly emphasised, or, as stated above, the illuminants employed should yield a spectrum resembling that of daylight as closely as possible. Fabrics appear in the colours which they reflect, and if the necessary component is absent in the artificial light the true colour of the fabric will not be revealed.

TABLE I.

Factory Service.	Intensity in Foot-candles.
General lighting without local lighting . .	2 — 6
General lighting with local lighting . . .	1 — 3
Local lighting—fine work	5 —10
Local lighting—coarse work	3 — 5
Drawing office	6 —12
Desk work	3 — 6
Small office (private)	3 — 4
Small office (general)	3 — 5
Large office—general lighting	3·5— 5
Large office with desk lights	1.5— 2
Warehouse	0.5— 1

Red, for example, looks purplish brown under the light of the mercury vapour lamp, since red rays are entirely absent from the spectrum of this particular illuminant.

Other characteristics which present themselves for consideration, such as diffusion and eye protection, are in many cases of equal importance to those already enumerated, but owing to lack of knowledge of their importance such characteristics are not generally appreciated, so much so that a detailed consideration of their value in the scheme of things is essential.

In the following table the characteristics which distinguish a good lighting system are enumerated:

Table II.

Characteristics of a Good Lighting System.
(1.) Efficiency. (2.) Uniformity. (3.) Diffusion. (4.) Eye protection. (5.) Colour value. (6.) Appearance.

A well-planned installation will combine the characteristics in their correct proportions, the degree naturally depending upon the class of installation and the lighting scheme involved.

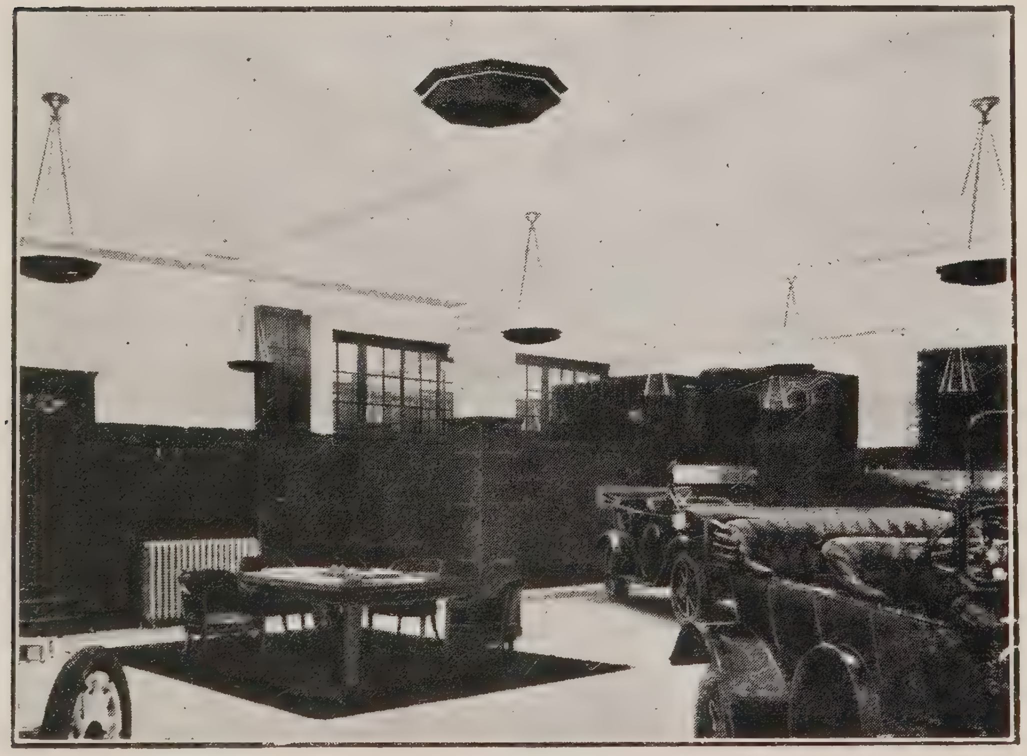


Fig. 1.—Artistic and effective lighting by the General Electric Company.

Thus, for example, although efficiency might be of primary importance in works lighting, it is of but little consequence in artistic lighting displays such as illustrated in fig. 1. At other times the colour of the illuminant may be the deciding factor, and if screens have to be employed to ensure a daylight result, the latter will naturally be considered before the efficiency of the installation. In drawing offices high intensity, absolute uniformity, and freedom from shadow are demanded, efficiency again being often sacrificed to this end.

Similarly each of the other characteristics will be the deciding factor in particular instances, and the following brief discussion should serve to bring out the relative importance of the various features enumerated in the table.

EFFICIENCY.

Efficiency in the strictest sense may be defined as the useful percentage of the total quantity of light produced by the lamp, or the ratio of the lumens actually reaching the working plane to the total lumens produced.

Useful light is the light remaining after subtracting that absorbed by the reflector and the walls and ceiling of the room illuminated, and when used in this sense efficiency is frequently termed utilisation or illumination efficiency.

OTHER CONSIDERATIONS.

While efficiency should never be lost sight of in the design of a lighting system, it is frequently desirable to sacrifice the same to some extent in order to emphasise some other factor. Efficiency should always be sacrificed, for example, in favour of eye protection.

Frequently, however, through inability on the part of the designer, efficiency is utterly disregarded, and consequently sacrificed with no gain whatsoever. It will always repay the trouble taken, more especially in large installations, to ascertain the cost of any sacrifice in efficiency in order to ensure that such sacrifice is justified, and also to check the calculations over before deciding upon a particular make of lighting unit to determine whether another, but equally satisfactory, kind could not be used to greater advantage.

UNIFORMITY.

A high degree of uniformity is a most desirable characteristic for the majority of interiors, and especially those in which a number of people are to be accommodated.

The necessity of gauging the opening of the pupil in order to protect the retina from the entrance of too much light, and yet retain the sensitiveness of the optic nerve endings, is a fatiguing factor when the iris is continually opening and closing as the eye shifts its direction of gaze from bright to less bright areas. The more nearly uniform the effect, the less the iris adjustment, and hence the less the fatigue. If identical illumination is received at every point of the working plane the illumination is uniform, or, in other words, if the number of lumens incident on each square foot of the working area is constant, the illumination is even.

Absolute uniformity is, however, never required in practice, and it is customary to express the degree of uniformity as the maximum deviation from the mean or average. Thus, if the average illumination in a room is 2 foot-candles, the maximum 2.4, and the minimum 1.5 foot-candles, the greatest deviation from the average is .5 foot-candles, or 25% of the average. The degree of uniformity would therefore be expressed as 25% maximum deviation from the mean.

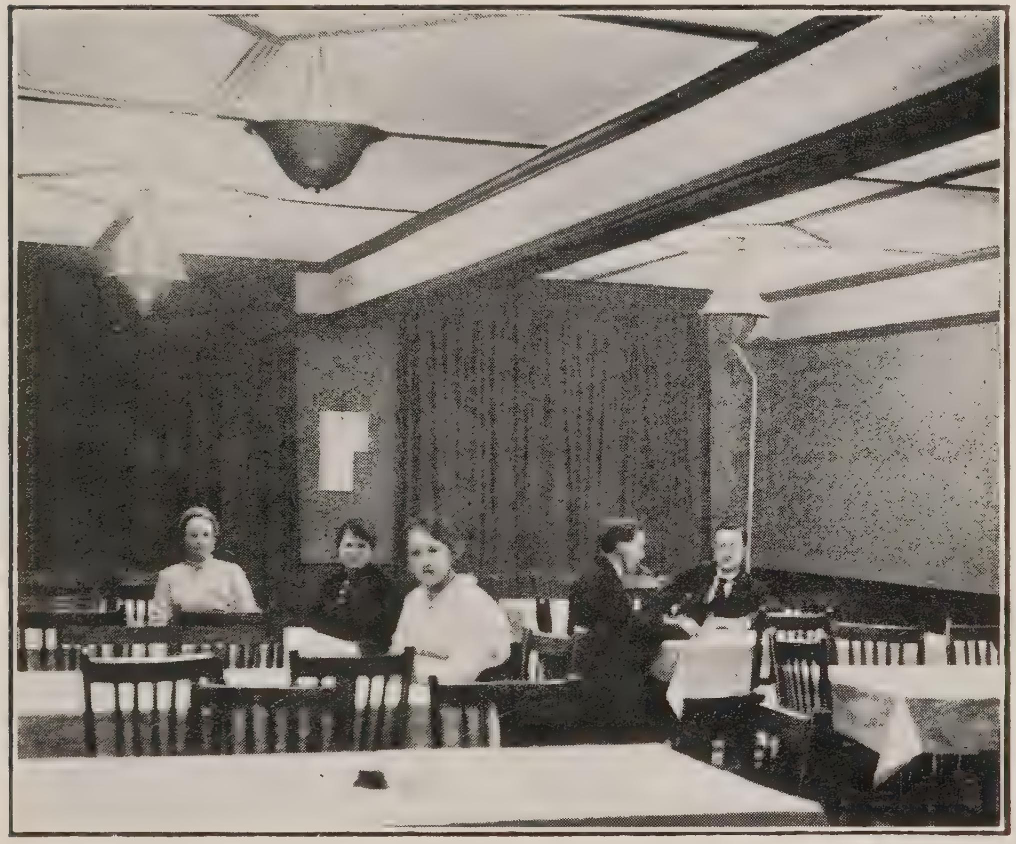


FIG. 2.—Efficient indirect lighting by the Wardle Engineering Company in the tea-room at a munitions factory.

Taking lighting systems in general, a maximum deviation of 30% from the mean may be regarded, for all practicable purposes, as uniform illumination, since the eye is unable to detect such a variation in the rooms usually met with in practice.

Considerably greater variations than this are frequently obtained in even well laid out installations, but in offices and factories and other places where close work is performed 30% is a desirable limit to work to.

In warehouses, many parts of factories and works, variations up to 50% may be allowed, while in such places as stock rooms still greater variations are not serious.

DIFFUSION.

Diffusion of illumination is an extremely important factor in many classes of work, and might be defined as the degree in which the illumination received at any point is composed of light coming from different directions.

Thus, if the illumination received at any point is composed of light coming from a great many different directions, the diffusion is good, but if from a few directions only, the diffusion is poor. In indirect lighting (fig. 2) the diffusion is excellent, since the whole of the light flux is directed on to the ceiling, which thus acts as a very large secondary source of light of low surface brightness, maximum eye comfort being thereby assured.

A high degree of diffusion results in the elimination of sharp shadows and the reduction of specular reflection from glossy surfaces, and is of vital importance in all drawing offices, for fine machine work, painting, and similar work.

An extreme case of poor diffusion will result from the employment of a single opaque reflector, the light then coming from one direction only.

Local lighting further results in annoying reflections taking place from the surfaces of polished metals, etc., and except in special cases is not to be recommended.

Uniformity of diffusion is of enormous importance in any room in which close work is performed, and a high degree of this characteristic is essential in such places as drawing offices, offices in general, and in shops in which fine work, such as fuse manufacture, is being carried on. The necessary degree may be obtained by a correct appreciation of the properties of the reflectors now available, and with correctly disposed reflectors and tip-frosted lamps the direct system of lighting will be found to provide adequate diffusion in factories and mills.

EYE PROTECTION.

Generally speaking, in order that the eye may exercise its functions correctly at all times, artificial lighting is relied upon whenever daylight fails, and the question arises as to the effect on the eye of the brilliant light sources so much in use at the present time.

Great strides have been made in recent times in the direction of increased intrinsic brilliancy and candle-power of luminous bodies, so much so that the eye has not had time to become what may be called educated up to the new conditions. The eye remains in practically the same state as it was when the candle was the principal illuminant employed, and at the present time is just as unfit as it was then to regard a naked light of high intrinsic brilliancy with impunity.

In this connection consider the effect on the eye of a single glimpse of the sun.

The nerves are injured to such an extent that distinct vision is an impossibility for some considerable time afterwards, and it is on record that, owing to the destruction of the optic nerve through such a cause, blindness has resulted.

Some such effect, although in a lesser degree, is produced every time an incandescent lamp with a clear bulb is regarded, and, although it is only recently that such a fact appears to have called for comment, one has merely to read in medical reports of the increasing number of cases of eye trouble, especially among children, to realise that some new cause is at work causing eyesight destruction, and without the slightest doubt unscientific lighting is in great part to blame.

As previously stated, the normal eye can regard with equanimity a source whose intrinsic brilliancy does not exceed 3-5 candle-power per square inch. An ordinary candle placed in the line of vision will thus not produce any harmful effect, but a glance at the following table, setting forth the intrinsic brilliancy of other sources, will make it clear that the eye should be protected from the necessity of ever looking at a brilliant source of light :

TABLE III.

Source.	Intrinsic Brilliancy.	
Sun at zenith	600,000	c.p. per sq. in.
Half watt lamp	8,000	,,
Nernst glower	800–1,000	,,
Tungsten lamp, 1.25 watt per candle	1,000	,,
Tantalum lamp, 2 watts per candle ..	750	,,
Carbon lamp, 3.1 watts per candle ..	480	,,
Frosted incandescent lamp, 25 watts, tungsten	4–8	,,

In any well-designed lighting system eye protection is afforded by the careful screening of the light unit. When reflectors are used they should be deep enough to cut off a direct view of the luminant at all ordinary angles of vision, and the lamp should be arranged at a sufficient height to eliminate all glare effect.

In this connection experiment has shown that the glare from a brilliant light source is most detrimental when the source is close to the line of sight. At 25° from the line of sight the glare effect has practically ceased. In fig. 3 the angle which includes light that may enter the eye with undesirable glare effects is shown, while it will also be clear that a deep bowl reflector covering the illuminant to an angle of 65° gives better eye protection than a shallow reflector.

The density of the glass used in the manufacture of reflector globes and semi-indirect bowls is another factor which has an important bearing upon eye protection. If too much light is transmitted the surface brightness of the bowl is too high to afford good protection to the eyes. Etched and ground-glass do not yield good results for this reason, while light density opal glass is not to be recommended, especially for half watt lamps and others of high intrinsic brilliancy. The object of artificial lighting is not to have lamps to look at, but to illuminate the objects in a room in such a manner that they may be seen distinctly and with comfort to the eye.

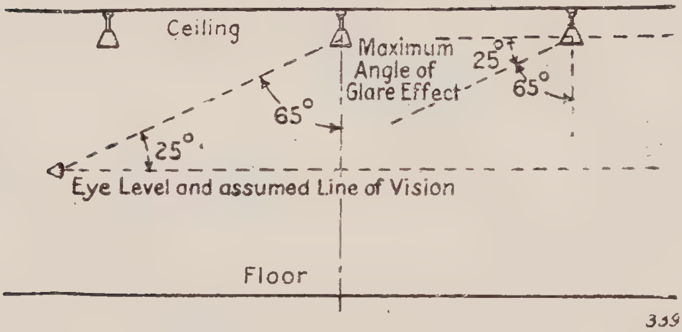

Ceiling
Maximum Angle of Glare Effect
25°
65°
65°
25°
Eye Level and assumed Line of Vision
Floor
339

Fig. 3.—The angle beyond which glare effect is obtained. The desirability of bowl reflectors is clearly shown.

Colour Value.

The colour value of the lighting unit employed is of great importance in all commercial work necessitating accurate colour discrimination.

For the successful performance of such operations as colour printing, lithographing, painting, etc., the spectrum of the luminous body must resemble that of daylight as closely as possible, and to meet these requirements special light units, of which the Holophane Truetint is a notable example, have been developed.

In ordinary work, however, it is generally unnecessary to consider the colour question except to avoid light sources whose colour is disagreeable or injurious to the eye.

CONCLUSIONS AND RECOMMENDATIONS.

The foregoing remarks should then make it evident that both from the employer's and the employee's point of view good lighting is essential. More so, it might be added, at the present moment, inasmuch as the conditions are abnormal. The majority of factories, and practically all the munition works, are running on overtime, while in many cases night shifts are in operation. This means that artificial lighting must be relied upon for many hours out of the twenty-four, and it should be remembered that many of the workers are practically strangers to the class of work upon which they are engaged. The conditions are unnatural, and in view of this, and the abnormal number of workpeople of both sexes that it is found necessary to employ, any cause that can effect an increase in the comfort of, and a decrease in the accidents attending, the workpeople is to be advocated. Again, the question of waste, before referred to, is frequently wrongly attributed to the pressing need of employing comparatively unskilled labour. Much of this waste, especially in munition factories, could be avoided if the workers had a sufficiency of light whereby to conduct their operations.

The whole question of factory lighting has indeed been too long in abeyance, but it seems as if the attention which is being paid to munition workers, who, after all, comprise the major portion of our factory hands, would have the effect of making adequate factory lighting compulsory.

The findings of the Home Office Committee on Lighting in Factories and Workshops are of great importance, and the committee state that they feel justified in proposing to make the subject one for legal regulation.

Quoting from their report, and in support of our previous statements, we note that the committee are of opinion that " in the designing of modern factories good lighting (both artificial and daylight) is now regarded as one of the most important factors contributing to industrial efficiency. On the other hand, it must be admitted that many employers have lagged behind in the general advance.

" This applies especially to factories designed before the importance of illumination was generally recognised and to small workshops on which the occupiers perhaps hesitate to expend the capital necessary for improvement.

" It is obvious that any requirements which would tend to bring such places up to the level of the more progressive firms would be beneficial not only to the operative by improving his working conditions, but also to the employer himself by increasing his output. Light is a cheap commodity, and little or no hardship would result from such a requirement if gradually and sympathetically enforced.

"There can be no doubt that the degree of comfort in the working conditions is largely determined by the adequacy of the lighting. The visits paid to factories have enabled us to realise not only the contrast between the depressing effect of dark surroundings and the cheerfulness of a brightly illuminated workroom, but also the vast difference in the working lives of the operatives that must result from continual employment under the two conditions.

"Finally, the necessity of prescribing adequate lighting in factories and workshops has long been recognised abroad, and the industrial codes of all the principal countries contain provisions requiring it in general terms.

"In view of these considerations we feel justified in recommending that a requirement in general terms for adequate and suitable lighting be applied to all factories and workshops."

The actual intensities required for different processes will be discussed in connection with the planning of installations, but for the moment it must be clear that the health of the workers is the first point of interest, and that one of the greatest factors in producing a cheerful, contented, and healthy workman is a sufficiency of correctly disposed light whereby to conduct his operations to the mutual advantage of employer and employee.

CHAPTER III.

THE DEVELOPMENT OF GAS LIGHTING.

IN the *Illuminating Engineer* for August, 1916, reference was made to the steady tendency towards co-operation between different sections of the lighting industry—a tendency that is illustrated by several recent discussions. Thus the report issued by the Committee of the Institution of Electrical Engineers, in connection with the projected Board of Trade Committee on Electrical Trades, has been the subject of comment in the gas journals, and the desirability of an analogous enquiry into some of the points raised in connection with the gas industry is suggested.

On the other hand, the electrical press, feeling the need for co-operative publicity, refers to the successful campaign undertaken by the British Commercial Gas Association on behalf of gas, and urges the necessity for a similar effort in furthering electrical lighting.

This watchfulness on the part of the advocates of each system is, we are convinced, all for the best, the tendency being to learn from each other and to rectify defects thus revealed in the several undertakings. Harsh criticism of opposing schemes by persons with an axe to grind is not in the best interests of the lighting industry, and the more the various systems of lighting are discussed the greater will be the advance made in every direction. There is room for gas, electricity, and oil, since each illuminant has its own particular sphere of usefulness, and an impartial attitude is the only one that will enable works managers and others to appraise the various illuminants at their true value.

Mr. Gaster, a member of the Departmental Committee on Lighting in Factories and Workshops, advocates a uniformity of policy at the moment as being more desirable in view of the problem of economising in coal supplies, and states that if full advantage were taken of the resources of illuminating engineering—*i.e.*, if properly designed reflectors and modern lamps and burners were judiciously used—an economy of 10% in the lighting bills throughout the country could easily be made. A saving of hundreds of thousands of tons of coal could thus be effected—a consideration at any time, but a vital one surely at the moment.

In many cases the local authority is responsible for both the gas and electrical undertakings, and we have in mind numerous concerns utilising both gas and electric lighting, and where a clearer insight into the correct use and applications of these illuminants would be useful. Such an insight may only be gained by the disinterested study and discussion of both illuminants, and we are happy to observe that the tendency is undoubtedly towards the closer co-operation of the two undertakings, the possibilities of joint effort being foreshadowed by Dr. Carpenter at a meeting of the South Metropolitan Gas Co., when he said, " I do not know whether the policy adopted by Parliament of putting suppliers of gas or gaseous and electrical energy into competition has not had its day ; it may have. If one were to begin again, one would not do what one is doing to-day, viz., put up a large station to produce electrical energy and another for gaseous energy. We should look to see whether these supplies should be undertaken separately, or whether there was not a great deal to be said, on the point of economical working, for running them together."

It is this spirit of co-operation that must be fostered, and the support of every lighting engineer, supply company, and contractor should be enlisted in view of the movement in the direction of increased popularity in artificial lighting, which is bound to come when the present war has been brought to a successful conclusion.

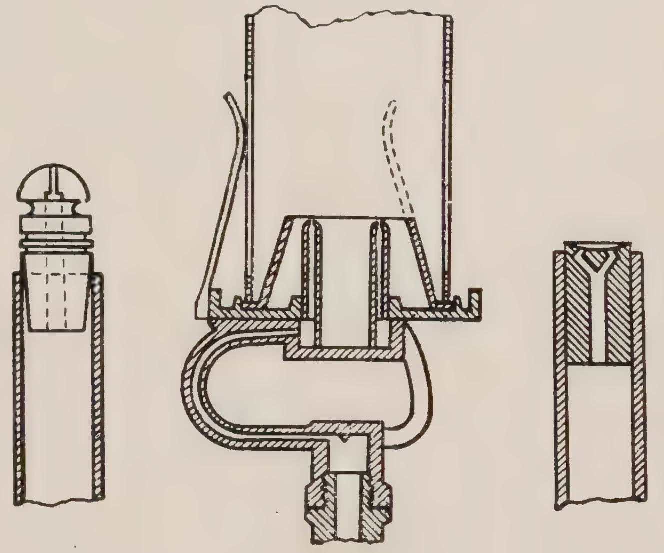
EARLY HISTORY OF GAS LIGHTING.

The earliest gas burners would appear to have simply been holes through which the gas was allowed to escape before ignition, although shortly afterwards it was found desirable to coat the burner tip with some refractory material such as steatite, which substance is almost universally employed in burners of similar type at the present day.

The form and size of the gas aperture was naturally a matter of importance, and numerous types of burner were developed, of which the " bats-wing " and " fish-tail " are perhaps the most familiar.

The tip of the fish-tail burner (fig. 1) is concave, and fitted with two small orifices so inclined that the gas jets impinge upon each other and spread out into a broad flat flame. There is naturally a tendency, however, for these holes to become choked with soot, so much so that fish-tail burners have been largely superseded by burners of the type known as bats-wing, consisting of a steatite dome having a narrow gas slit.

Other types of open flame burners are the Argand and the regenerative burner. The Argand, which is now little used, except as a standard burner in gas testing, consists of a hollow perforated steatite ring, from which the gas is allowed to issue. The cylindrical flame is surrounded by a glass chimney, the draught-inducing action of which is such as to bring air into contact with both sides of the flame, and so promote the most efficient and uniform luminous combustion. The long flame is, however, unsteady and readily affected by draughts.



Bats-wing. Argand. Fish-tail.

FIG. 1.

Regenerative burners utilise the waste heat of combustion to pre-heat the gas and air supply, and thus improve the efficiency.

The whole of the burners mentioned provide a luminous flame, as distinct from the Bunsen or non-lumnous flame used in connection with incandescent gas lighting. Two zones may be distinguished in the luminous flame, the outer, consisting of a non-luminous envelope of hydrogen and other gases in a state of rapid combustion, and an inner zone of heavier hydrocarbons. The latter are decomposed at a high temperature, and liberate incandescent particles of carbon, which glow with incandescence until consumed or carried away as smoke.

Judged by present-day standards, all flat-flame burners are naturally very inefficient, burners rated at 4 cubic feet per hour yielding only 2.5 candle-power per cubic foot of gas of ordinary quality.

With well-adjusted Argand burners the value may be increased to between 3 and 3.5 candle-power per cubic foot, while regenerative burners yield a duty of almost three times this amount.

In addition to the low duty yielded by all such flames, a portion of the gas escapes unburned and vitiates the atmosphere, while flat flame burners are further inclined to smoke, and in general furnish a very unsatisfactory and unscientific lighting unit.

In face of these facts, it is therefore surprising to find that enormous numbers of such units are still in use in every part of the country.

It is still more surprising, since the works manager as a rule values anything that will effect an improvement in the turnover and quality of the products, for which reason it has been a general practice for many years past to consider most carefully the *daylight* lighting of factories and workshops. Inverted saw tooth roofs, large glass areas, the construction of small bays, and adequate use of the northern sky are all factors in determining a sufficiency of good natural light. The workman is generally well catered for, and has at his disposal an ample illumination from a large number of light sources, good diffusion and freedom from glare being thereby secured. Such is only to be expected in any well-organised factory, but, unfortunately, a very different tale is to be told when it comes to the question of artificial lighting by gas.

Until the advent of the incandescent mantle, gas lighting was most unscientific, and the British Commercial Gas Association states that in one large manufacturing town alone nearly 50,000 flat flame burners were still in use a year or so ago. Obviously under such circumstances the operatives must work under very trying conditions, for there is a great contrast between the ample correctly directed natural light and the inadequate artificial substitute when daylight fails.

Mr. Thorp gives some interesting figures in this connection. As the result of a large series of tests in factories, he found that the average daylight illumination was 32 foot-candles and the minimum 8.6, whereas only .63 and .62 foot-candles were obtained in the same factories with the aid of flat flame burners. To increase this value in the old days naturally meant an increased cost, additional light sources, and an increase in the amount of heat produced. The advent of the incandescent mantle has, however, entirely changed the outlook, and with inverted burners and pressure gas there is now no excuse for the artificial lighting falling short of the most exacting requirements.

NATIONAL INSTITUTE [illegible] PSYCHOLOGY.

As previously stated, the ordinary flat flame burners cannot exceed from 2-3 candle-power per cubic foot of gas of ordinary quality. A modern incandescent mantle in a correctly designed lantern will yield 40 c.p. per cubic foot of gas per hour and over. It will thus be clear that with modern units the available candle-power can readily be increased at least ten times, with an enormous gain in overall efficiency, and at a decreased running cost into the bargain. The manufacturer, in fact, pays far more for indifferent lighting than he does for good lighting, with all its attendant advantages.

It is merely a question of educating the user to the real and immediate gains of a good lighting installation, for when once the idea has been grasped that good lighting pays, no matter from what aspect the situation is viewed, then the day of the flat flame burner and all such units will be over.

The Incandescent Mantle.

The advent of the incandescent mantle entirely changed the aspect of the gas lighting industry, which began to feel the need for higher candle-power and more efficient burners on the introduction of electricity.

In incandescent mantle lighting, a non-luminous or Bunsen flame is essential, the gas being fully aerated before combustion and the luminous effect prevented by the rapidity of oxidation. The Bunsen flame, in common with the luminous flame, also exhibits two zones, the inner, a conical bluish green one, and the outer surrounding zone, which is the region of oxidation and is entirely non-luminous. In the incandescent mantle an entirely new principle is therefore involved, for the gas is used simply as a heating agent in order to raise a web of suitable material to incandescence. The fundamental idea was evolved as early as 1826 by Drummond, but it was not until Welsbach discovered that a cotton fabric soaked in rare earth solutions and then burned left a residue of great strength, refractoriness, and luminous properties that the incandescent mantle received serious consideration.

The early mantles were, however, disappointing from the standpoint of durability until the further remarkable discovery by Welsbach of the effectiveness of a 1% mixture of ceria to the thoria in the mantle paved the way to a lasting success. It is interesting to note that there is a certain value, about .9% to 1% of ceria, which gives the best possible results, and that any increase or decrease is prejudicial, this percentage being said to be adhered to without much variation even in mantles of present-day make.

According to Wickenden, thoria is a poor radiator capable of maintaining a high temperature, but inefficient in the production of light. Ceria possesses remarkable radiating power, but cannot alone maintain the high temperature requisite for efficient luminosity. A combination of the two, in which the ceria is in a finely divided state, is able to maintain a high temperature and give a highly efficient light emission. The ceria is often termed an excitant oxide.

The quality and lasting properties of a mantle are exceedingly important points, and a series of disasters with poor mantles may lead a manufacturer to decry the whole gas lighting industry. Good lasting qualities are more than ever of importance at the moment in view of the guaranteed long life of electric lamps, and before deciding upon a particular make of mantle, works managers should satisfy themselves that durability and maintenance of candle-power are strong points.

The quality of a mantle is largely determined by its initial candle-power, mechanical strength, and the ability to maintain both the quality and quantity of the light output through a satisfactory period of time. These factors, it is hardly necessary to add, are largely dependent upon the quality of the fabric employed, the condition of the gas supplied, and the skill exercised throughout manufacture.

STEPS IN THE MANUFACTURE OF INCANDESCENT MANTLES.

Since mantles vary so much amongst themselves, and the burning-off process is so little understood, it may be of interest to gas users to trace the steps in the manufacture of a modern mantle. In every case a web of suitable material must first be formed, and afterwards immersed and uniformly impregnated in a solution containing the thoria-ceria mixture. After drying, the web is burned away, the active material being left in the form of a skeleton mantle, which obviously should hold together in a fairly durable condition. To facilitate transport, this skeleton mantle was at first invariably steeped in collodion, and it is this collodion coating which has to be burned off by the consumer before the mantle can be used in the ordinary way. Recently, however, it has been found possible to dispense with this process, while the cotton, which was at first exclusively used for mantle manufacture, has been replaced by Indian hemp, ramie fibre, and, more recently, artificial silk. A good mantle should not split or tear through impact with the flame when lighting up, it being a sign of mechanical weakness if such is the case. The mantle should also be durable from a light-giving point of view, and, when operating, should be enveloped in the hottest zone of a Bunsen flame, and, further, supplied with a mixture of gas and air so proportioned that at constant pressure the hottest flame consistent with stable combustion results.

Collodion coating being open to objection, mainly on account of the burning-off process injuring the mantle to a certain extent, so-called soft mantles have recently been developed. These consist merely of the impregnated fabric, which, not having been subjected to the burning-off process, is therefore strong and durable. When first placed in service, the mantle is burned off, and automatically adapts itself to the shape of the flame, thus conforming to the conditions just instanced for efficient burning. Soft mantles may be stored without deterioration, and may even, it is said, be dipped in water without ill-effects.

The greatest advance has been made, however, in the direction of the mantle material. Formerly cotton was exclusively used, and afterwards ramie fibre. The introduction of artificial silk has resulted, however, in a great improvement. The silk threads are much longer and more uniform, and microphotographs indicate that, even after 1,000 hours' burning, the fibres are still quite uniform. Nass states that on a high pressure gas lamp silk mantles have lasted for seven weeks, while ramie mantles of similar character would only last six days.

It has further been stated before the American Illuminating Engineering Society that the light deterioration during 1,000 hours was from 35-40% with cotton mantles, 15-20% in the case of ramie, but that under favourable circumstances there was no perceptible diminution in light with silk mantles in 2,000 hours, and only 5-10% after 4,000 hours of burning.

Such, of course, are laboratory results, but no doubt a considerable improvement is to be obtained in practice.

High pressure mantles are subjected to a continuously higher temperature and greater flame velocity, and must be of great mechanical strength. To obtain greater durability double mantles, one inside the other, are frequently employed.

INCANDESCENT BURNERS.

In addition to the mantle, a variety of other causes tends to influence the efficiency of the average gas lamp. The temperature attained is a deciding factor, and this in its turn is dependent upon the calorific value of the gas. The pressure of the gas supply also greatly affects the intensity and the efficiency of the unit, while the burner itself is no mean factor in deciding the result.

Vibration has an effect on a mantle, and must be guarded against, special anti-vibration fittings being available where conditions are such as to warrant their use. (Fig. 2.) The new varieties of inverted mantles are, however, practically immune from vibration effects, the fact that such mantles are largely used for train lighting bearing evidence on this point.

With regard to the burner itself, it is essential that the most perfect regulation of the gas and air should be secured, corresponding with the quality and pressure of the supply. All modern gas lamps are provided with devices to secure the necessary regulation, and it is important to note that once the necessary regulation to secure maximum results has been attained no further adjustment should be made. In this connection it is interesting to observe that the South Metropolitan Gas Co. has introduced a form of burner which is adjusted once and for all for the quality of gas on this company's supply area, and can therefore be used without means of gas and air regulation.

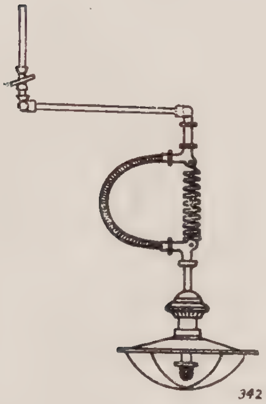


FIG. 2.—An anti-vibration fitting.

The adjusting mechanism of the Ukay lamp (fig. 3) is interesting in this connection. From the maintenance standpoint the most vital part of the lamp is the gas injector, and this, it will be gathered, can be screwed out of the burner without dismantling the lamp in any way, and cleaned and replaced in a moment or two. This feature alone is claimed as sufficient to distinguish the Ukay lamp as a suitable type for works lighting, and especially for use in dusty positions, where it is essential that the construction of the lamp should be such that the burners can be kept clean with the minimum of trouble.

A further distinctive feature is the air adjuster, the burner being fitted with a sliding liner, which is adjustable towards or away from the gas injector. This seems to be a great improvement on the usual rotatable sleeve air adjuster, and imparts a higher velocity to the gas and air mixture with resulting increased illuminating power.

Instructions for a first adjustment are issued by the manufacturers, and are, of course, of interest in general. Thus, before putting on the mantle, it is necessary that the Bunsen flame should be quite clear and bright, and have a well-defined centre of a greenish blue colour surrounded by a purple flame. A smoky blue colour with a very faint centre indicates too much gas or not enough air. It will usually be found necessary to have the air adjuster fully opened. Lastly, it is advised that the mantles should not be quite filled at first, but that the lamp should be given a few minutes to get thoroughly hot, and then more gas admitted until a dark spot appears at the bottom of the mantle. The supply should then be reduced until the spot just disappears.

After the lamp has been adjusted the adjustment must not be interfered with, because the mantles do not attain full brilliance immediately on being lighted. A rapid improvement will take place as the lamp becomes heated.

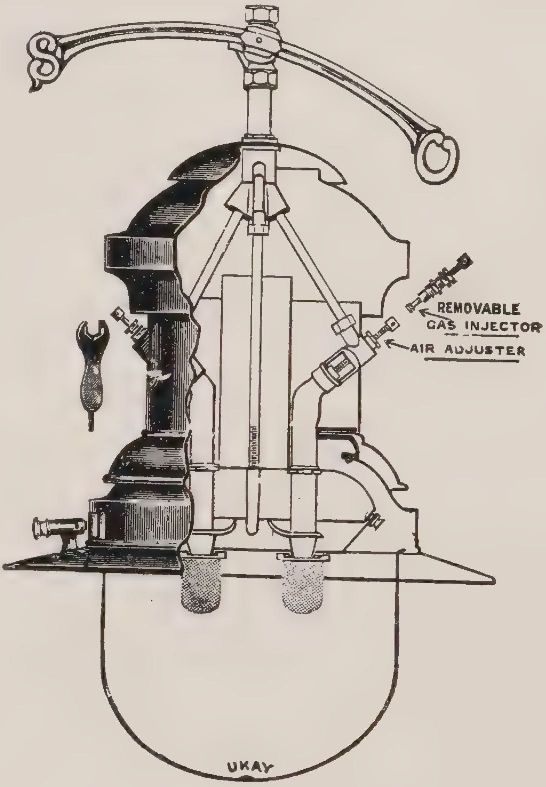


FIG. 3.—The Ukay lamp.

The Ukay is a low-pressure unit, and yields about 125 candle-power per burner, consuming four cubic feet of gas per hour.

In the Bray, Welsbach-Kern, and Bansept burners, to instance a few of the better-known varieties, the design is such as to ensure the most intimate contact of the gas and air, in the latter a series of conical chambers, each opening by a small orifice into the one above, being employed. The design of the mixing chamber is, in fact, one of the salient features of a modern burner.

Good modern low-pressure burners can be adjusted to work on practically any supply pressure, but if pressure fluctuations cause inefficient burning, it might pay large undertakings to install some efficient regulating device at the meter.

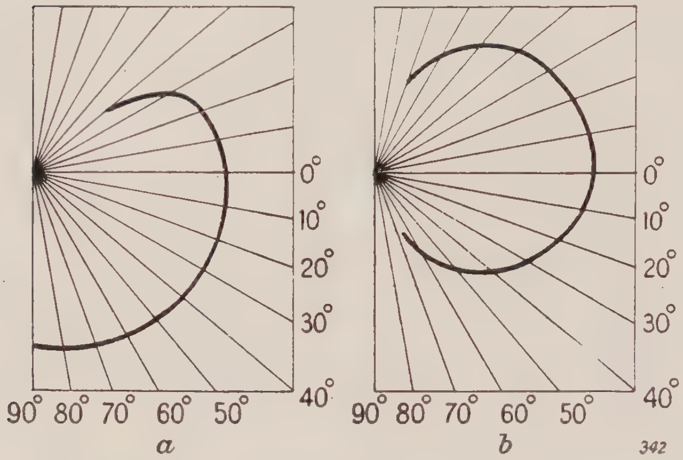


FIG. 4.—Polar curves of light distribution from inverted and upright mantles.

LIGHT DISTRIBUTION OF GAS ILLUMINANTS.

The distribution of light from any luminous source, such as an upright or inverted gas burner, may be determined with sufficient accuracy if a number of candle-power measurements are made at intervals of 10° in a plane passing through the vertical axis of the source.

The measured values are plotted with polar co-ordinates from the luminous source as centre, and a smooth line joining the points gives the polar curve of light distribution.

Thus, in fig. 4, polar curves, indicating the light distribution from typical inverted (*a*) and upright mantles (*b*), are shown.

Such curves merely afford an indication of the candle-power in any direction, and no other meaning must be attached to them. The area enclosed by the curve is frequently taken as a measure of the light output of the source. This is not the case, however, although it is possible to compute from the curve the mean spherical candle-power, and from this latter value to determine the total light output of the source.

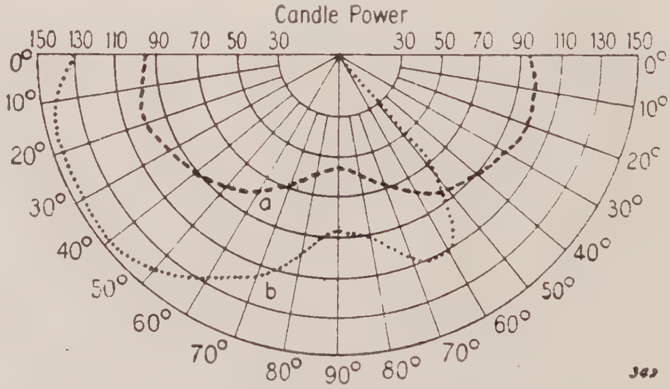


FIG. 5.—Polar curves: Symmetrical and unsymmetrical sources.

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In the figure one half of the distribution curve only is shown. In reality there are two such curves, one on each side of the vertical, but for symmetrical sources it is only necessary to indicate one, fig. 5 (*a*). On the other hand, for unsymmetrical sources the full curve must be provided. This will be evident from fig. 5 (*b*), a study of which will make it clear that there is a preponderance of light on the left-hand side. This result has been obtained by the employment of what is known as a parabolic reflector (fig. 6), the effect of which is to transfer the major portion of the light from the right to the left side. Such a distribution is desirable in many cases of factory lighting, *e.g.*, in lighting more or less vertical surfaces and the binns from which goods are issued from a store.

Fig. 6 illustrates a low-pressure unit, but in figs. 7 and 8 the application of high-pressure Tilley units of similar design is illustrated. It will be noted that the lamps are used for local lighting, and for concentrating on to particular pieces of work. General lighting is also provided by means of Tilley high-pressure high candle-power units. Both figs. 7 and 8 are typical of what might be termed mixed lighting, *i.e.*, general lighting by means of high candle-power units and a further concentration where necessary by local units. Attention might also be directed to the anti-vibration device, a useful adjunct if abnormal vibration leads to excessive mantle breakage.

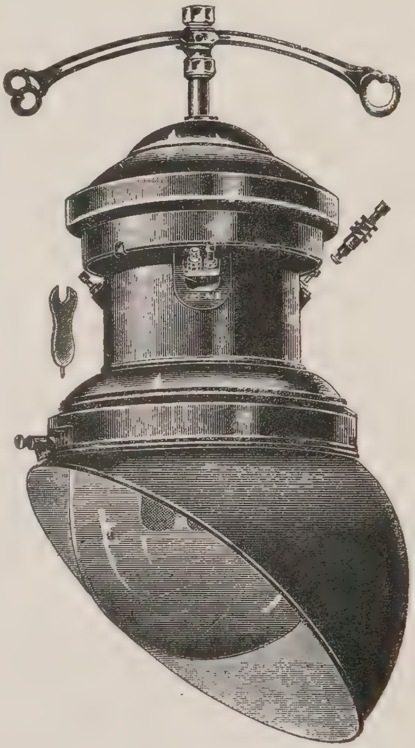

FIG. 6.—A parabolic reflector for factory lighting.

DERIVATION OF ILLUMINATION CURVES.

Having obtained the photometric curve of the light unit, either from the reflector manufacturer or by direct test, an illumination curve may easily be derived for any particular mounting height of the lamp above the working plane. The latter is the plane on which the chief illumination is desired, and is generally assumed to be 2ft. 6in. above the floor.

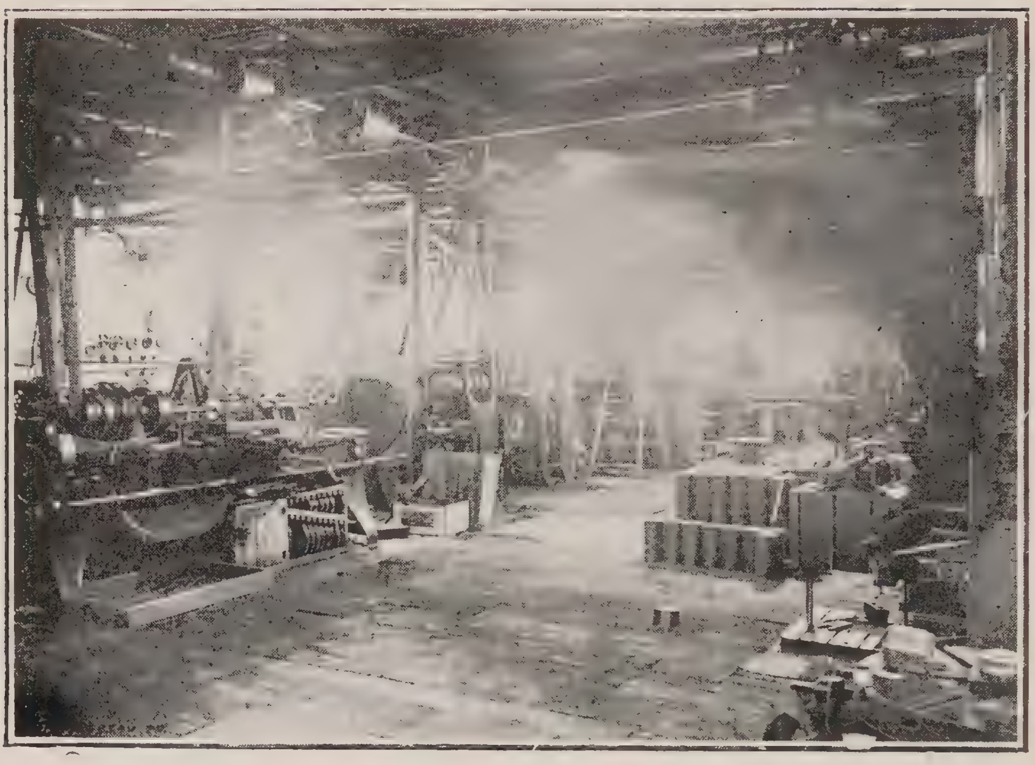

FIG. 7.—General and local lighting by Tilley high-pressure gas lanterns.

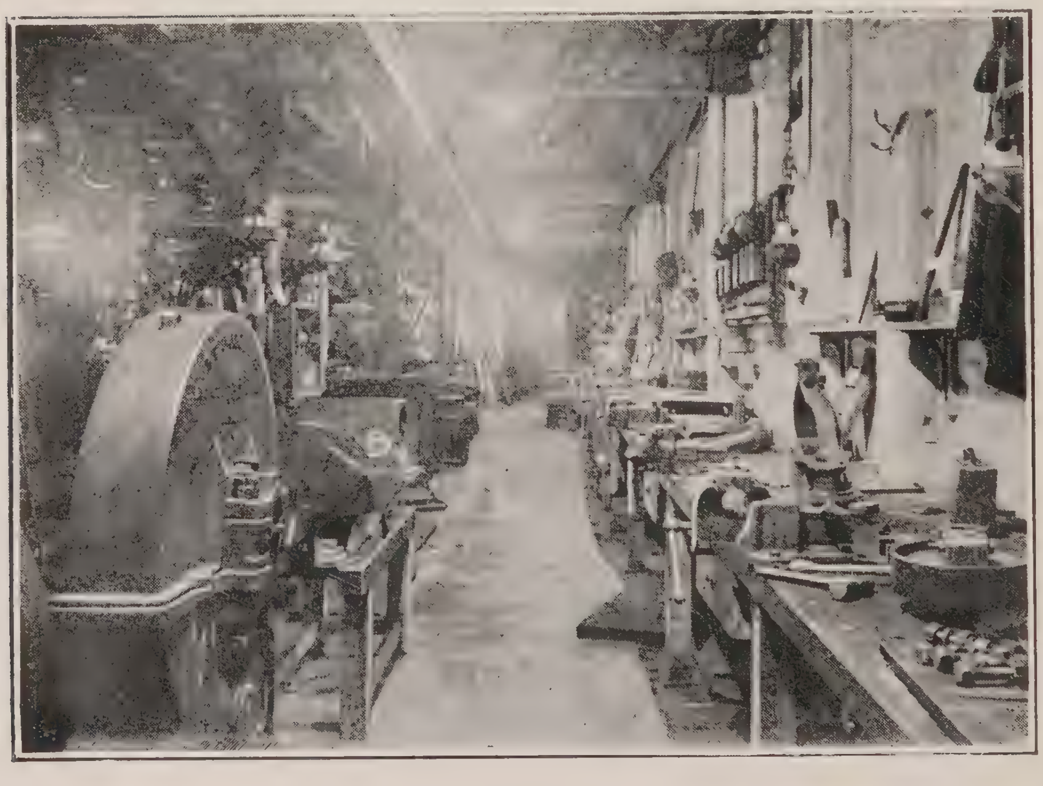

FIG. 8.—Bench and general lighting by Tilley high-pressure gas lanterns.

The illumination curve is extremely useful, and shows in a graphic manner the intensities in foot-candles on a horizontal plane at various distances from a point directly underneath the light unit. In fig. 9 the polar curve of a low-pressure 1,000 c.p. three-mantle lamp is given, and the illumination curve plotted for a mounting height of 20ft. above the working plane. The formula will be developed in the chapter on electric lighting, but for the moment it will suffice to state that the horizontal illumination at any point is given by $\frac{CP}{H^2} \cos^3 \theta$. Where CP is the candle-power in the direction of the point considered, H the vertical height in feet of the light unit above the plane illuminated, and θ the angle of incidence, or the angle made between the direction of the ray and the normal at the point.

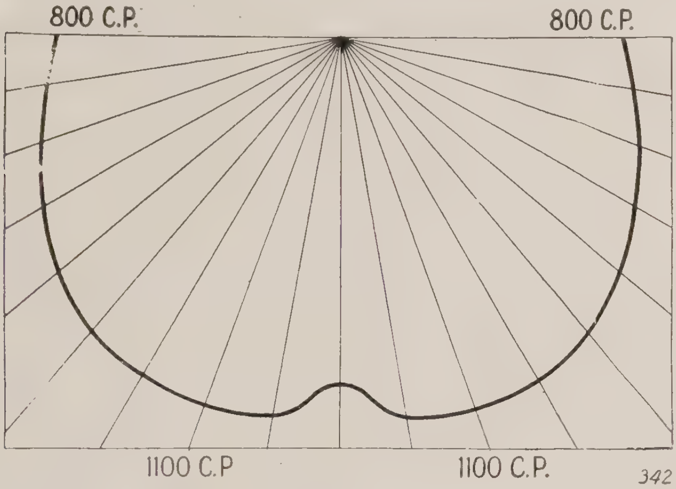

FIG. 9.—Polar curve of 1,000 c.p. three-mantle, low-pressure gas lamp.

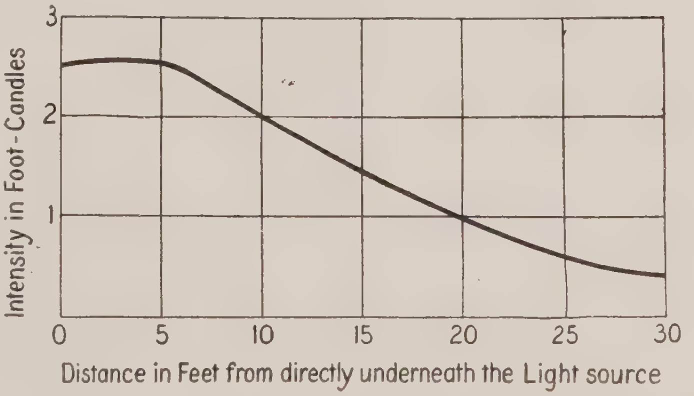

FIG. 10.—Illumination curve derived from the polar curve (fig. 9). Height of lamp, twenty feet above the working plane. Curve for a single lamp only.

With the illumination curve at hand, it is an easy matter to determine the distance apart at which the units should be spaced in order that the resulting illumination may be even, or that the maximum variation from the mean should not exceed some prearranged value. The eye, it will be remembered, is unable to detect a variation of less than 30% in a room which is receiving a general illumination, which value will provide a figure to work to. For example, it will be seen that, in order to secure an even illumination of an average value of three foot-candles, the units illustrated in fig. 9 should be suspended thirty feet apart.

In using photometric curves to judge of the value of light units, due consideration should be given to the value of the light in the various zones. In the average installation the light emitted in the zone 90° to 60° is usefully employed. Light emitted in the zones above this may serve a useful purpose if reflected as diffused reflection from the ceiling, but otherwise it is used inefficiently on account of cross reflections between the walls and ceiling. What is of still greater importance, the zone 30° to 0° includes the light which enters the eye directly from the unit under average conditions of vision.

A study of the curves provided will make it evident that the maximum intensity — candle-power simply being measured as an intensity in any direction—in the case of the upright burner is afforded in a horizontal direction, while, on the other hand, the inverted burner throws nearly the whole of its light in a downward direction.

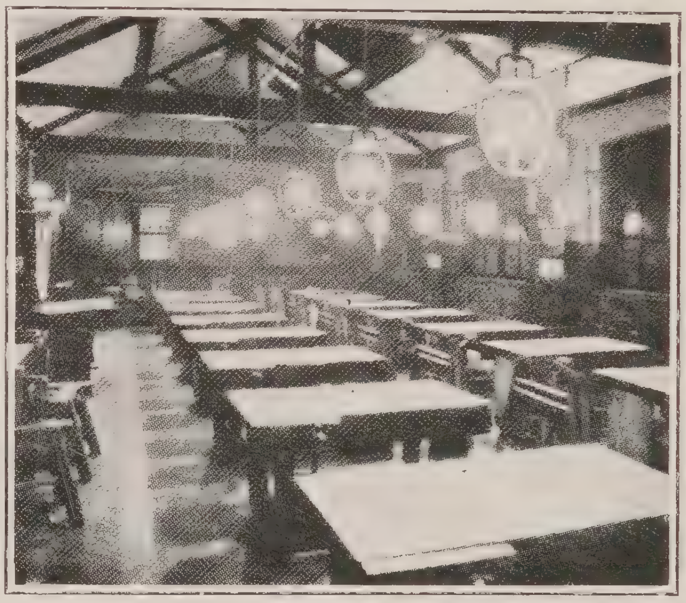

FIG. 11.—Upright burner lighting in relation to work benches.

A much greater variation in candle-power can also be secured with the inverted mantle, small units of as low a value as 25 c.p. and high-power multiple units of thousands of candle-power being available. It will be clear also that the inverted mantle obstructs very little of the light, whereas the upright burner from its very nature obstructs a large portion of the emitted light. This naturally leads to an improved efficiency in the case of the inverted mantle, and to a more favourable distribution of the light. It is interesting in this connection to compare the modern flame arc, the polar curve of which somewhat resembles that of the inverted mantle, with the D.C. open arc, in which the maximum intensity is afforded at an angle of approximately 45°, the intensity directly underneath the lamp being zero.

Further additional advantages of the inverted burner are clearly demonstrated in figs. 11 and 12, where the general plan of the lighting in relation to the work benches is very similar, and the bench illumination in both cases almost identical. The quantity of gas consumed by the inverted installation is, however, only 70% of that consumed by the other, while the shadow effect is distinctly less in the former case.

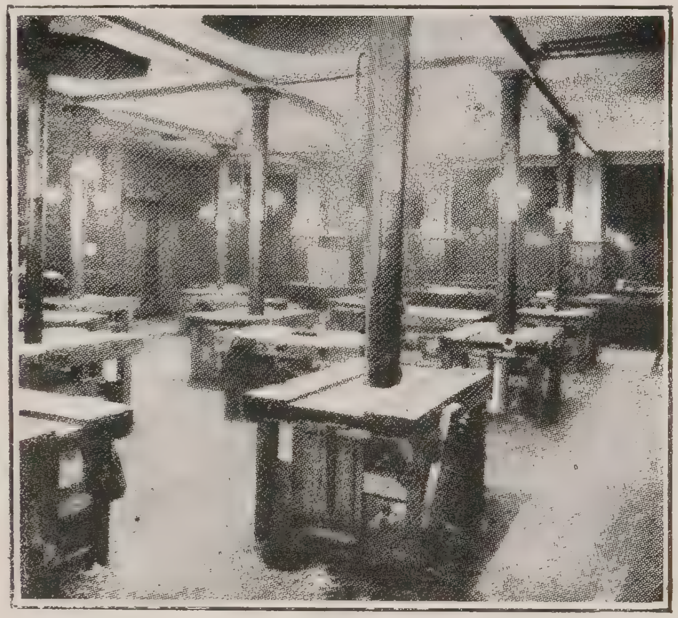

FIG. 12.—Inverted burner lighting in relation to work benches.

These figures make it clear that gas lighting can be installed in accordance with the recognised rules of good lighting, and that a workshop can be adequately and suitably lighted by either the upright or the inverted system. The adoption of the inverted in place of the upright system leads, however, amongst other things, to a considerable saving in running costs, and to reduction in the shadows produced.

CHAPTER IV.

MODERN PRACTICE IN GAS LIGHTING.

Influence of Reflectors.

THE main functions of a reflector are to shield the eye of the worker and to redirect the light in the most useful directions, while protection should also be afforded to the mantle and burner.

Reference to fig. 4 (*b*), Chapter III., will indicate the immediate necessity of a reflecting device in order that the major portion of the light emitted may be usefully employed. Without some reflecting device the ceiling and walls would receive the greater portion of the emitted light, and since in the majority of factories the reflecting properties of such surfaces leave much to be desired, the light would be wasted and serve no useful purpose whatever.

The behaviour of a reflector depends almost entirely upon its design and the nature of the reflecting surface. Thus three varieties of reflection are distinguished according to the manner in which the various surfaces reflect the light. These varieties are direct, spread, and diffuse reflection. Direct reflection takes place from the surface of mirrors and polished metals, and while such surfaces afford a high degree of light control, they are very little used, except for head lights, etc., on account of the streaked character of the resulting illumination.

Spread reflection somewhat resembles direct reflection in that the maximum intensity of the reflected light is in the same direction as in direct reflection. The light is broken up, however, and spread from the direct path. Aluminium or similar matt surfaces produce spread reflection, and such reflectors are capable of very accurate design.

In diffuse reflection the direction of the incident light has no bearing on the reflected beam, the maximum intensity of the reflected light always taking place at right angles to the surface. Opal, porcelain, and paint enamel provide diffuse reflection, and extreme distributions cannot be obtained with this character of reflecting surface.

The laws of light transmission are exactly analogous to the laws of reflection, and direct, spread, and diffuse transmission may be obtained with different classes of material. Clear glass affords direct transmission, etched, ground, or sand-blasted glass spread transmission, while diffuse transmission is yielded with opal.

The laws of reflection and transmission have a vital bearing on the design of reflectors and enclosing glassware, and while the problem of the choice of a reflector for a particular class of work is a simple one to the expert versed in lighting matters, it is a different matter entirely when an amateur with practically no lighting knowledge attempts to make a selection. The laws underlying the construction of the reflectors must first of all be thoroughly understood and then, guided by the resulting polar curves and bearing in mind the characteristics of good lighting, some degree of success may be attained. As in all things, experience is the best instructor, and, before embarking on any particular scheme the opinion of experts should be obtained or experimentation in a small way should first of all be attempted. Remember that the first essentials of any good lighting scheme are the comfort, health, and consequent efficiency of the worker, and that afterwards economy with maximum efficiency at the lowest possible cost must be the objects striven for.

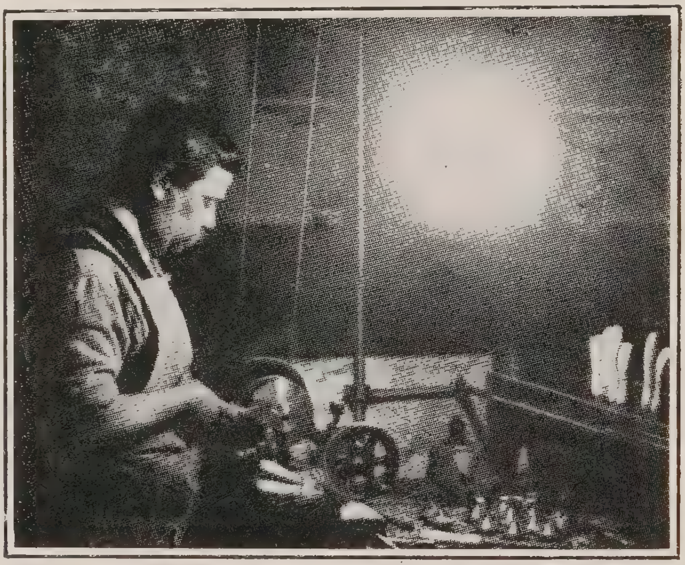

FIG. 1.—Faulty local lighting.

Reflectors are not a great advantage to sources which themselves direct the greater portion of their light in a useful direction, but correctly designed reflectors can largely increase the mean lower hemispherical candle-power of such sources as the upright gas mantle, which of itself emits a large part of its light in the upper hemisphere.

In addition to redirecting the light, the reflector should also serve to decrease the surface brightness of the source when the latter falls within the line of vision, or otherwise the light should be completely screened by the reflector surface.

As stated, the human eye can regard with equanimity a source whose candle-power does not exceed some 2-5 candle-power per square inch. Approximate figures for low-pressure incandescent gas sources are 10-30 candle-power per square inch, while with high-pressure installations the intrinsic brilliancy ranges from 50-300 candle-power per square inch of apparent area, the latter being calculated in the direction of maximum candle-power. It will thus be obvious that, unless the lighting units are so mounted as to be above the line of vision, some device is needed to shield the eyes of the worker—in both his own interests and those of the work.

Inadequate screening of the light sources unfortunately frequently obtains in practice, with the result that a large amount of light is needlessly wasted, and frequently so directed as to be a hindrance to the workers and, in many cases, a positive danger. Figs. 1, 2, and 3 are interesting in this connection. Fig. 1 depicts a workman attempting to carry out some work at the lathe while at the same time receiving the light from a bare incandescent mantle full in the face. Under these circumstances it is impossible for the man to carry out his operations with any degree of accuracy or skill. Excessive brightness produces images which are abnormally intense, causing injury to the retina. The pupil contracts in its effort to protect the eye, thus reducing the amount of light entering the eye and rendering the work indistinct, even though sufficiently well lighted for normal requirements.

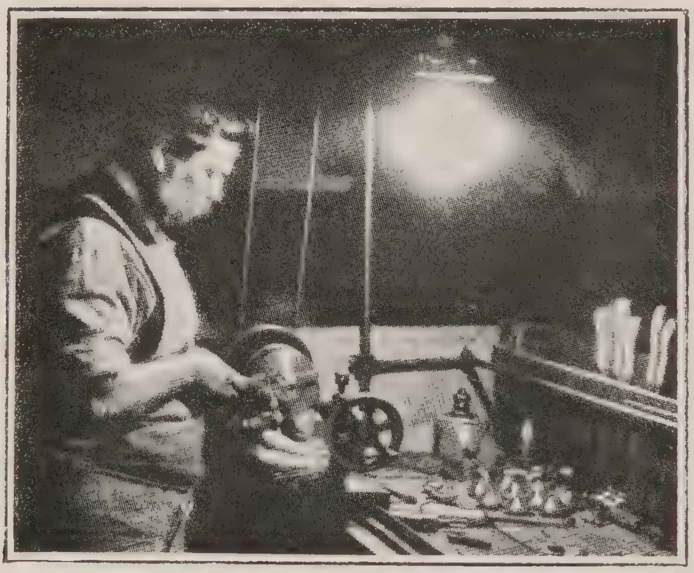

FIG. 2.—Indifferent local lighting.

It must be clearly understood by all users of powerful light sources that the latter, when exposed to view, constitute a prolific source of eye trouble, and that under such conditions a worker suffers from temporary or partial blindness—an effect generally referred to as glare.

Fig. 2 shows a partial improvement. The reflector provided, however, does not completely screen the light source, and part of the latter is still in view. All such reflectors should be condemned, and their places taken by ones similar to that shown in fig. 3, in which the ideal local lighting conditions are portrayed. No direct light can possibly enter the eyes, while it should further be noted that the light which was formerly wasted is now all directed on to the work and usefully employed. There is thus a distinct gain in both visual and physical efficiency.

Necessity of Lighting Reform.

In view of the large number of unshaded local lighting units in use in engineering workshops at the present day, recognition of the significance of the facts illustrated in figs. 1, 2, and 3 is of vital importance, and indicates one line along which the reform of gas lighting should proceed.

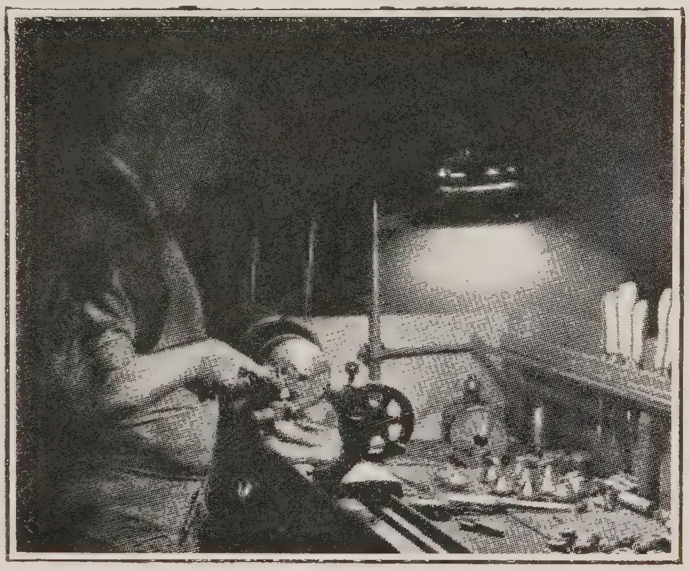

Fig. 3.—Correct local lighting.

In far too many cases works officials are happy in the provision of a single flaring source for each employee. No reflector is provided, the source throws most of its light in the wrong direction, while the workman is further hampered through receiving direct light full in his eyes. In all cases adequate screening should be provided, and antiquated units of the bats-wing variety replaced by up-to-date inverted mantles embodying a correctly designed reflector. An actual saving in running costs may readily be effected, and the whole of the additional advantages of a good lighting scheme secured into the bargain.

Choice of Reflector.

The choice of a reflector naturally depends upon the conditions. When the light sources have simply to be protected from dust, currents of air, etc., it is sufficient to surround them with globes of transparent glass. Bearing in mind the recommendations regarding surface brightness, it will be seen, however, that the necessity arises for further screening if no injurious effects are to arise. In places where glass reflectors are desirable a translucent reflector of sufficient density should be employed to ensure a surface brightness of from 2-5 candle-power per square inch. The eye may then regard the reflector without suffering injury, while work may be carried out with the maximum of comfort to the worker.

It must be borne in mind that the use of reflectors and globes always reduces the available light output of the source, since part of the light is absorbed by the reflector itself. The necessity for cleanliness will be at once apparent, and a study of fig. 5, Chapter I., will enable the approximate date for cleaning to be determined.

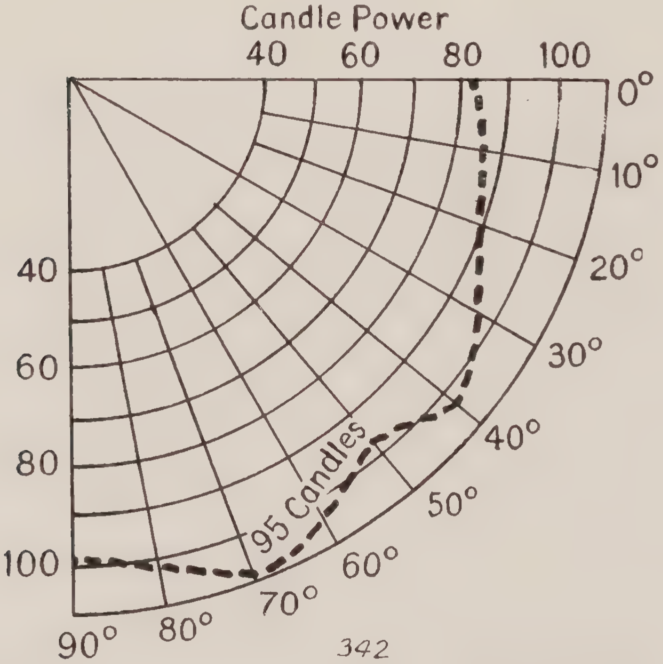

Fig. 4.—Polar curve of light distribution of a bare incandescent mantle.

For industrial purposes sharp shadows are objectionable, and in many cases, foundries for example, a positive danger. The shadow effect is merely a question of the spacing of the lighting units, an increase in the area of the reflecting surface producing an increase in the area of the light-giving surface, with a reduction in the shadows produced. The application of a correctly designed reflector will further serve to improve matters, for the light may be directed where it can be most usefully employed, and not scattered in all directions, as would be the case without reflector or if an incorrectly designed one had been used. This point is well brought out in fig. 4, which affords a graphic representation of the candle-power in various directions of a bare incandescent mantle. It will be noted that the candle-power vertically downwards is almost 100, at 50° from the horizontal practically the same, while a very large amount of light is emitted in the almost useless zone 0°-30°. Fig. 5 gives the polar curve of light distribution of the same source, consuming exactly the same quantity of gas as formerly, when provided with a simple form of reflector, a section of which is shown in the sketch. The candle-power in a vertical direction has been increased by almost 100% at the expense of the light formerly emitted in an almost useless direction. The light is now directed where it is most required, downwards on to the work, and a clear gain in efficiency is at once established without, it should be observed, any extra expenditure in gas consumption. This curve is characteristic of the distribution to be obtained from conical reflectors and inverted mantles, and is of the intermediate or intensive pattern. Other distributions have already been indicated in figs. 5 and 9, Chapter III., from which it will be evident that the efficient distribution of light is merely a question of the use of appropriate reflectors, and is, moreover, just as important a question as that of efficient light production. Light in the wrong place is worse than wasted, for it almost invariably causes discomfort, if not actual injury to the eyes of the workers.

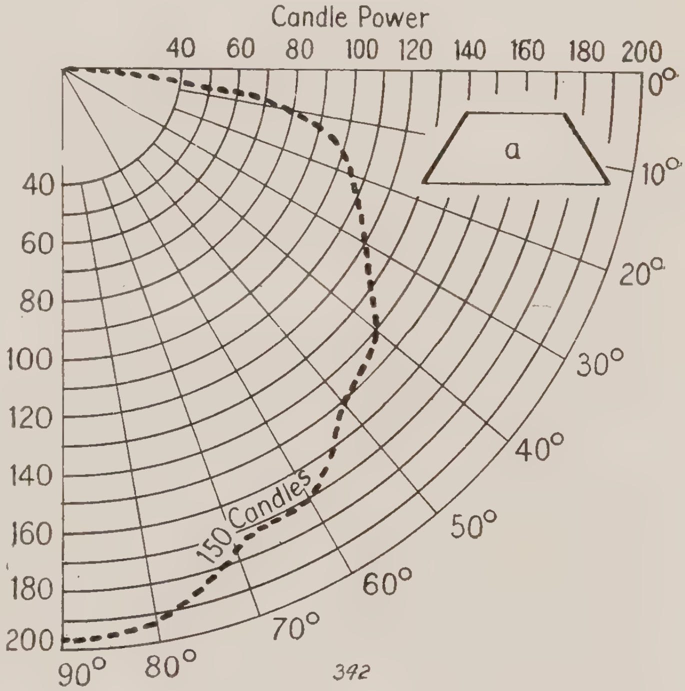

Fig. 5.—Polar curve of light distribution of mantle and reflector.

THE PLANNING OF LIGHTING INSTALLATIONS.

Many light users are apparently under the impression that in order to use light sources efficiently the latter should be suspended as close to the work as possible. For this reason, then, thousands of workpeople are condemned to work with a glaring light source within the line of vision. Actually the height of the lamp does not influence the efficiency in the slightest, for, provided that correctly designed reflectors are employed and the units spaced according to the rules instanced above, equal intensities of illumination may be secured with varying suspension heights. The higher the lamps are placed the more nearly the conditions approach natural ones, since our main source of light, the sun, is so placed as to be out of the direct line of vision entirely. Bearing these points in mind, works lighting may be treated under the following heads :

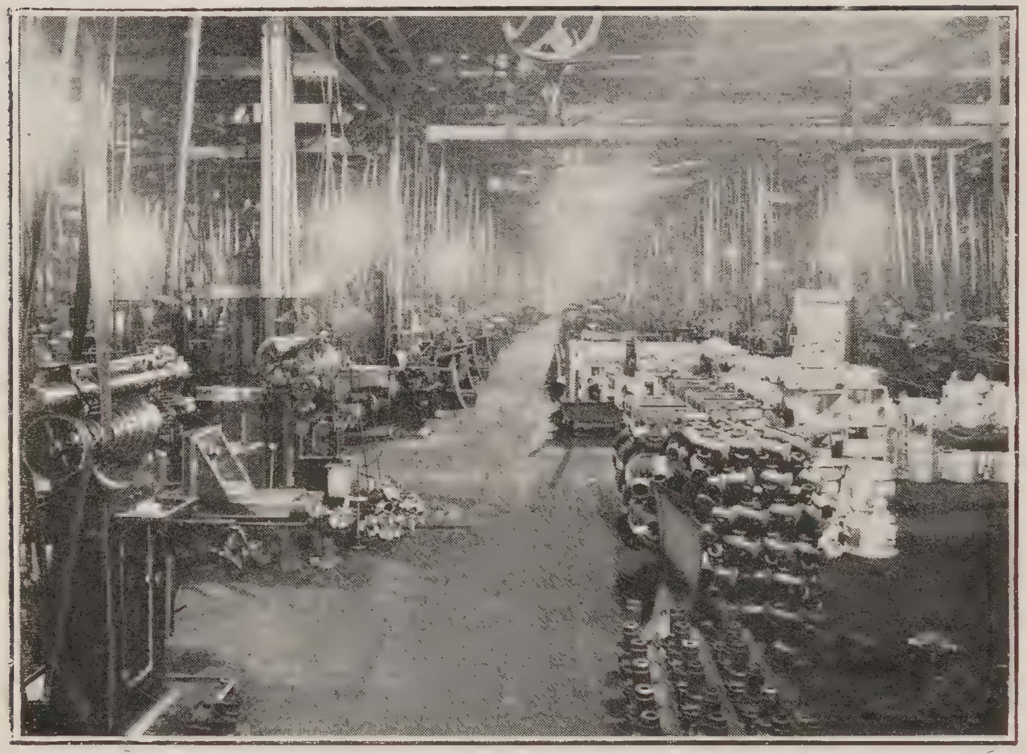

FIG. 6.—Machine shop at the Napier Co.'s works.

(1.) General lighting.
(2.) Group lighting.
(3.) Local lighting.
(4.) A mixture of local and general lighting.

In *general lighting* the room is lighted as a whole without reference to the work carried out in any particular part. The lighting, of course, should be adequate and satisfy the requirements of good lighting, and for such places as paint shops, foundries, assembly rooms, stores, etc., general lighting leaves nothing to be desired. Figs. 6 and 7 afford excellent examples of the application of general lighting by gas to workshops and factories. Fig. 6 shows the machine shop of the Napier Co.'s motor works, and it will be observed that a comparatively small number of large units are employed and hung well up out of the line of vision. For large rooms of this nature the use of high candle-power units is to be advocated. The height is favourable to the use of powerful sources, and the large area to be lighted means that all points receive light from a number of light sources. Hence the diffusion is good. Fig. 7 affords another excellent example of the same principle, the view room of the Napier Co.'s works being illustrated in this case. The glass screens placed round the mantle and reflector will be noted.

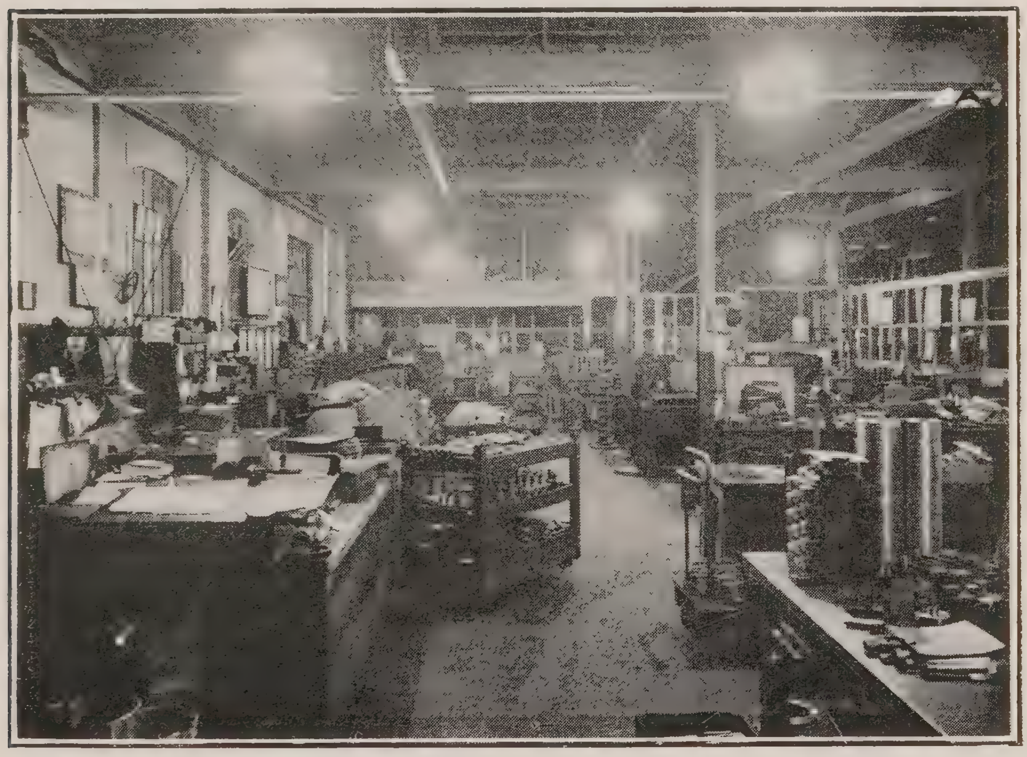

FIG. 7.—View room at the Napier Co.'s works.

Fig. 8 is a magnificent example of general lighting, a daylight effect being produced, while the high candle-power units suspended well above the cranes are completely out of the line of sight. Some local lights will also be observed where a specially high intensity is required.

Group lighting consists in lighting a row of machines or a certain working area by general lighting. The light units are arranged to suit the work, which is concentrated on, and the correct intensity and direction are fixed without regard to the requirements of the rest of the room. This arrangement is possible whenever a large number of similar machines are to be dealt with, and will be found suitable in the case of light metal work, metal spinning, etc. (fig. 9.)

Local lighting is the lighting of a piece of work or of an individual machine irrespective of the lighting of the remainder of the room. The effect is produced as a rule by means of a single lamp and reflector, and the unit should always be arranged in such a manner that the light is received on the work and not in the eyes of the operator. Local bench lighting is illustrated in fig. 10, a number of low-pressure lamps fitted with conical reflectors being used after the manner of group lighting. Local lighting, except in special cases, is, however, not to be advocated, since it is inadvisable to place the light unit under the control of individual workmen. When used, however, local lighting should always be supplementary to general lighting of low intensity, otherwise disagreeable contrast effects hinder the progress of the work.

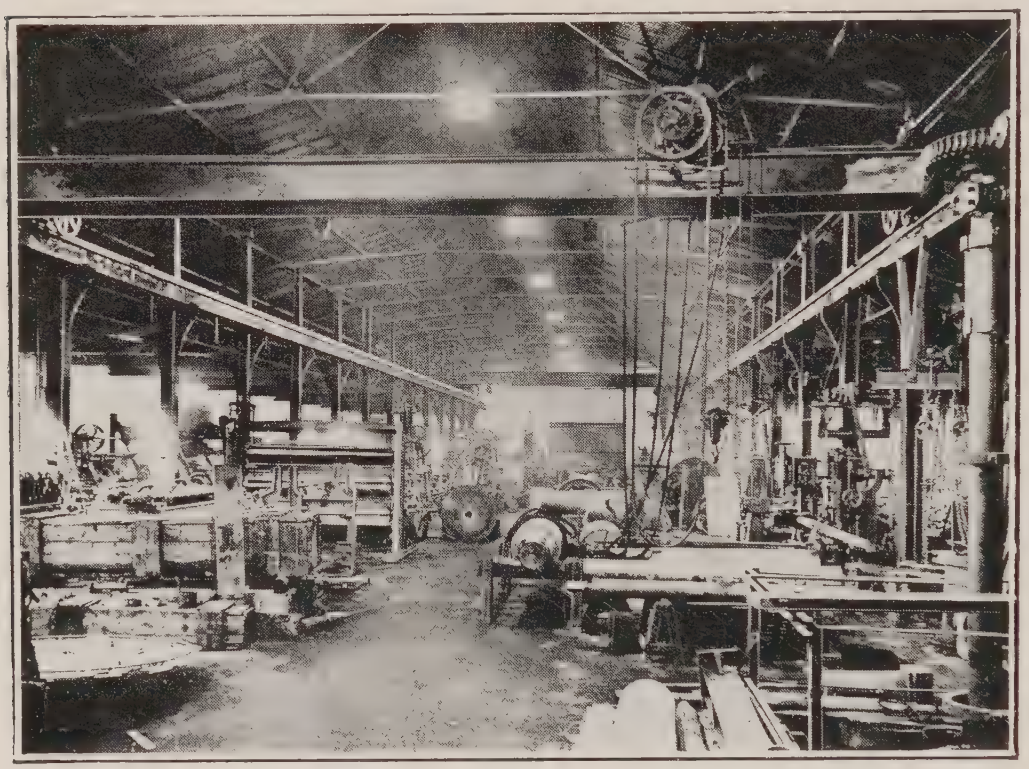

FIG. 8.—Main shop at Messrs. Masson, Scott and Co.

HIGH AND LOW PRESSURE SYSTEMS.

In concluding the present chapter, a brief description may be given of the two systems of gas lighting in common use. The British Commercial Gas Association, with reference to the matter, states: "It must be pointed out that in many workshops it is expedient to use gas at ordinary low pressure in spite of its being less efficient in respect of candle-power obtained per cubic foot of gas consumed. The choice between high and low pressure depends on several circumstances, the chief of which are (1) the size of the workshop or factory, and (2) its distance from an existing high-pressure supply. It may be pointed out here that what is called ordinary 'low-pressure' gas, such as is distributed in the ordinary supply mains, exists at a pressure equal to a column of water from three to five inches high, according to the district; that is less than one-sixth of a pound to the square inch. What is called 'high-pressure' consists of the low-pressure gas compressed by a machine until it exerts a pressure equal to a column of water 70in. to 100in. high, or approximately 3 lb. to 4 lb. per square inch—a very low pressure as compared with the pressures used in steam or hydraulic practice. The pressure adopted depends upon local circumstances, and may readily be altered if necessary by adjustment of the machine.

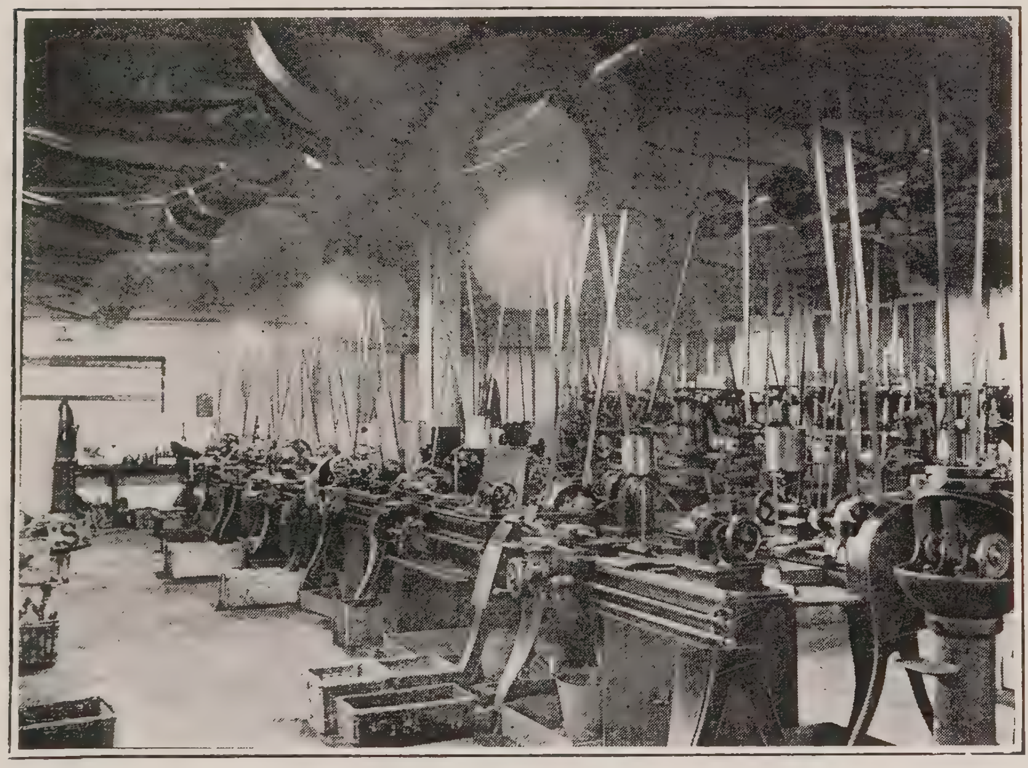

FIG. 9.—High-pressure gas lighting at the Triumph Cycle Co.'s works.

"COMPARATIVE COSTS.

"It will be seen from the above statement that the production of high-pressure gas demands the use of a compressing machine, and clearly the cost of running such a machine, together with the charges on its capital cost (which must be added to the price of the gas before the relative advantages of low and high-pressure systems can be properly compared), must bear some relation to the size of the installation. This point will be readily appreciated by anyone accustomed to balance the *pros* and *cons* of alternative methods in general works management.

"It frequently happens, however, that a high-pressure gas supply exists in the neighbourhood, in which case the problem assumes a different form, since the advantages of high-pressure gas can then be provided without incurring running costs or capital expenditure other than that necessary for an extension of the pipe line.

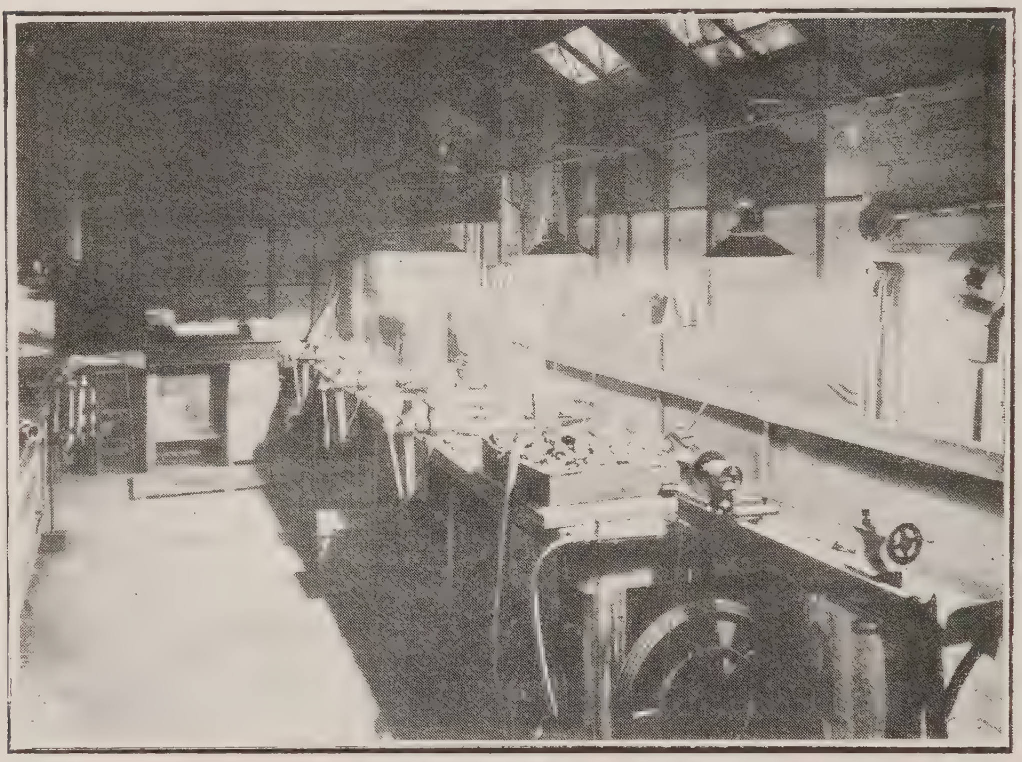

FIG. 10.—Bench illumination by means of local lighting.

"Where an isolated machine would have to be provided, it will usually be found expedient to adopt low-pressure gas if the total candle-power required is less than 1,000 candles, unless, as frequently happens, high-pressure gas is needed for purposes other than lighting. As, however, the conditions of supply vary in different parts of the country, factory managers are strongly urged to seek the advice of their local gas suppliers before deciding on any definite scheme."

Otherwise, as far as the recommendations of the Home Office Committee apply, all that has been said on the subject may be regarded as equally applicable to both high and low-pressure incandescent gas lighting. The illustrations of the Napier Co.'s Works and of those of Messrs. Masson, Scott, and Co. (figs. 6, 7, and 8), are all of high-pressure systems, while figs. 10 and 11 are illustrations of low-pressure lighting. Fig. 10, as already explained, is representative of correct local lighting, which should be employed under similar circumstances whenever a small area demands a high degree of illumination. The lamps are each of 60 candle-power, and furnish an illumination of 10 foot-candles immediately beneath the lamps and 6-5 foot-candles midway between. A good seeing light is also provided on the floor, the actual value being 1.7 foot-candles, undue contrast being thus avoided. Fig. 11 illustrates general low-pressure lighting, and the even character of the resulting illumination will be specially noted. The two photographs give an excellent idea of both local and general lighting, bringing out the salient features of each class of installation and clearly indicating that the employment of a particular system is entirely dependent upon the nature of the work carried out.

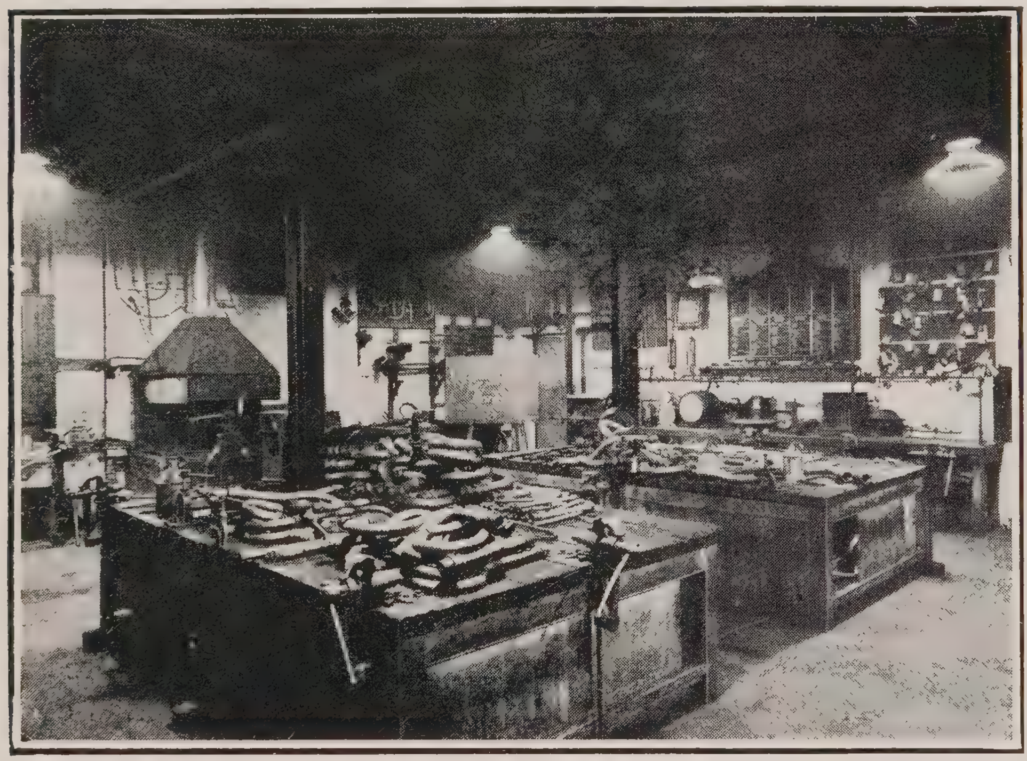

FIG. 11.—General low-pressure gas lighting.

CHAPTER V.

PROGRESS OF ELECTRIC LIGHTING.

THE credit for the first incandescent electric lamp belongs, properly speaking, to Sir Humphry Davy, who succeeded in producing an arc between two carbonised wooden rods by the application of a voltaic pile of 2,000 plates. Commercial dynamos intended for the production of electric light were first built about 1866, but it was not until 1878, when Brush introduced his series arc lighting system, that electric lighting established itself on a successful commercial basis. The development of the Brush system in conjunction with the famous electric candles of Jablochkov is now generally conceded to have laid the foundation stone of the arc lighting industry, and the first installation, it is interesting to recall, was made in Cleveland in 1879.

The early arc lamps provided a fairly satisfactory lighting unit for large areas and outdoor use, but were not capable of meeting the demands of the individual consumer, so much so that numerous early inventors worked with the object in view of perfecting the small lighting unit. One of the earliest investigators of the incandescent electric lamp was Edison, and he appears to have been among the first to appreciate the fact that variable numbers of high resistance lamps could be run in parallel on constant pressure circuits.

Edison introduced the first commercial lamp in 1879, the filament being horseshoe-shaped, and made of carbonised paper. The efficiency at which the lamp operated was 7 watts per candle, but this was improved later to 5.8 watts per candle by the adoption of a carbonised strip of bamboo. The life of the lamp was also increased by this change, but even so the candle-power decreased approximately 20% in the first 100 hours. Further improvements in 1881 increased the efficiency to 4.6 watts per candle, and a test made under the auspices of the Franklin Institute in 1884 on carbon filament lamps of five different manufacturers showed an average consumption of 3.16 watts per candle. This latter figure is very rarely exceeded even at the present day—carbon filament lamps being variously rated at 3-4 watts per candle-power—from which it will be evident that very little change has taken place in the efficiency of carbon lamps during the last thirty years. In fact, carbon, having proved a suitable substance for filament manufacture, held the field with practically no opposition until comparatively recent times, manufacturers apparently taking it for granted that a departure from carbon was an impossibility.

GEM LAMPS.

The next important step in the development of the incandescent lamp was the "metallisation" of the carbon filament. By raising an ordinary carbon filament to a high temperature in an electric furnace the cold resistance of the filament is very much reduced, and the temperature coefficient is further changed from negative to positive. In addition, the refractoriness of the filament is increased—sufficiently so, in fact, to permit of its operation at a temperature some 200°C higher than that of a carbon filament for equal deterioration. A considerable gain in efficiency is the nett result of these changes, the Gem lamp operating at an efficiency of 2.5 watts per candle as compared with 3.1 watts per candle for the carbon lamp.

METAL LAMPS.

To achieve success in filament form a metal must possess several very important properties. To permit of its continuous operation at high temperatures it must be refractory, and it has long been known that many metals can withstand much higher temperatures than carbon without excessive disintegration taking place. Carbon is the most refractory material known, and the temperature of the arc crater is stated by various authorities to vary between 3,000°-4,000°C. Yet, in spite of this fact, tantalum and tungsten are much more satisfactory materials from the filament point of view. The metals certainly have a lower melting point, but possibly, by reason of their high atomic weights, they can be operated continuously at a higher temperature, their rates of evaporation from the solid state being much lower than that of carbon. The temperature limit of the filament is then not so much the melting point as the temperature at which evaporation is such that the life of the filament is unduly shortened.

TUNGSTEN LAMPS.

Tungsten has been found by experience to be the most successful metal from the filament point of view, and the filaments of all modern glow lamps of repute are manufactured exclusively from this metal. Good drawn wire tungsten vacuum lamps operate at an efficiency of approximately one watt per candle, and are about four times as efficient as the ordinary carbon lamp. This is an exceedingly important point, and, in view of the findings of the Lighting Committee, economy and increased light output should be studied, and, whenever possible, carbon lamps replaced with the more efficient metal ones. It will thus be seen that since the invention of the glow lamp there has been a constant increase in operating efficiency, with the result that the user has been continually receiving lamps of higher candle-power for the same power consumption, and, since prices have also decreased to a great extent, consumers have been largely benefited.

THE BEST LAMP.

Every lamp user is naturally interested in finding out which is the best lamp for his own particular service. That he fails to do so is too often the result of accepting the statements of unscrupulous lamp dealers that the best lamp is the cheapest. The fallacy of this contention lies in the assumption that a lamp's value is to be measured solely by its first cost instead of by its ultimate cost. The first cost, or price of the lamp, is but a fraction of the ultimate or true cost, and takes no account of the useful life of the lamp, its efficiency, or the cost of energy, themselves the most important factors of a lamp's cost. A simple example will readily convince the reader of what a small percentage of the ultimate cost the first cost of the lamp really is. A 32 c.p. carbon lamp, for instance, will consume about 120 watts and have a useful life of, perhaps, 700 hours. At 3d. per Board of Trade unit, the cost of the energy expended during this interval will equal 21s., being the cost of 84 units at the price stated. The cost of the lamp in question will be in the neighbourhood of 1s., the total cost being, therefore, 22s., and the ratio of the lamp cost to the total cost less than 5%. We see, therefore, that, while the first cost of the lamp at this particular life and efficiency is but 5% of its ultimate cost, the cost of the energy consumed is over twenty times that of the lamp itself. Again, we may ask ourselves if the best lamp is the lamp which lasts the longest or gives the longest actual life. Considering this aspect of the question, a moment's thought will convince the reader of the fact that actual life has no bearing on the question of useful life, for the lamp may continue to run long after blackening of the bulb has decreased the light output to almost a vanishing point. Further, actual life ignores efficiency, cost of power, and also the initial cost of the lamp itself, from which it must be obvious that length of service is no criterion of a lamp's quality. Experience, in fact, actually teaches the reverse, for exceedingly long life is usually only attained at the expense of candle-power and efficiency. Lamps must yield a satisfactory light output as well as length of service ; that is, their life must be a useful one, or life with a high percentage of the rated candle-power.

The conclusion to which we are then forced is that the best lamp, and, incidentally, the cheapest, is not the lamp which sells at the lowest price, nor yet the lamp which lasts the longest, but is the lamp whose ultimate cost is the lowest, or with equal price and efficiency the lamp which yields the longest useful life.

Modern Factory Lighting.

Equal progress has also been made in the direction of arc and mercury vapour lighting, and for all modern industrial purposes electric light may now be considered as standard, high efficiency tungsten lamps, arc lamps of the flame and regenerative type, and the mercury vapour lamp representing the most recent practice as far as the light units themselves are concerned. The introduction of the latest lighting unit—the half watt type metal filament lamp—has indeed practically solved the question of efficient industrial lighting, for in addition to seriously challenging the efficiency of all other high candle-power light sources, it bids fair to cause a widespread replacement of lamp clusters and arc lamps of the more ordinary kind. The greater simplicity, convenience, and general adaptability of the half watt lamp will cause its general adoption in place of all lamps whose construction involves a mechanism and moving parts.

The half watt lamp possesses all the advantages of the ordinary metal lamp, in addition to its own inherent advantages. Summarised, the advantages are :

(1.) No moving parts or mechanism, adjustment being neither required nor permitted.

(2.) The lamp is complete in itself.

(3.) Equal satisfaction on either alternating or continuous current service, and during series or parallel operation.

(4.) The lamps may be used on any frequency down to and including 25 cycles per second, provide a non-inductive load, and are available for all standard voltages from 25 to 260 volts.

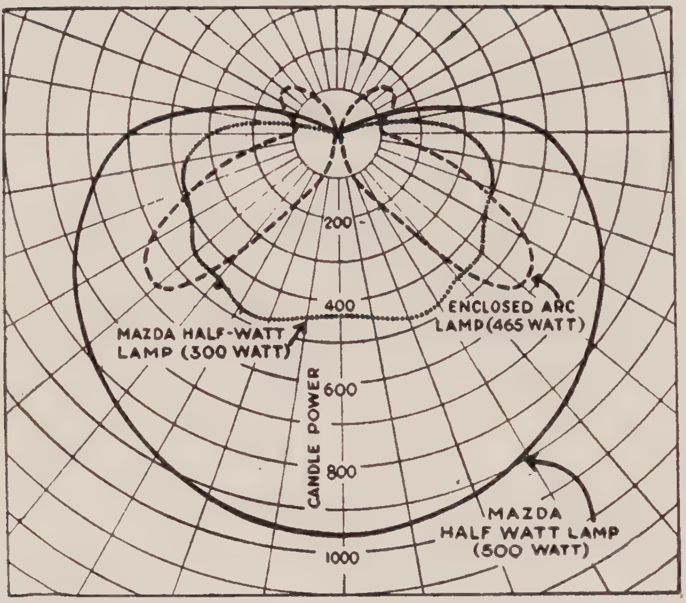

FIG. 1.—Comparison of candle-power distribution curves from enclosed arc lamp taking 465 watts—clear outer and inner globes and Mazda half watt lamps taking 300 watts and 500 watts respectively, with Alabas globe.

(5.) A complete range of sizes from 15-1,500 watts is available, permitting of the use of a number of distributed lights in place of arcs, etc., of equivalent candle-power, a condition securing the ideal for uniform lighting.

(6.) Half watt lamps can be used in conjunction with reflectors of suitable design to secure any required distribution or concentration of light, especially in the lower hemisphere, the filament of the lamp being shaped to promote this feature.

(7.) The light of the half watt lamp is steady, soft, uniform, and of a satisfactory colour, while the lamp itself is simple, silent when running, and comparatively inexpensive as far as the first and running costs are concerned.

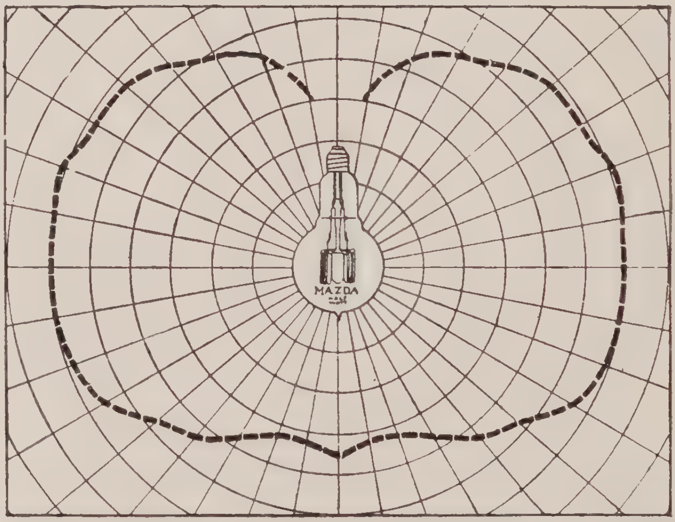

FIG. 2.—Characteristic light distribution of Mazda half watt lamps, 500-1,500 watt type.

(8.) Lastly, the efficiency is very high, being in the larger sizes almost double that of the ordinary metal filament lamps and eight times that of the ordinary carbon filament glow lamp.

The flame arc, regenerative arc, and mercury vapour lamps provide the only serious rivals to the half watt lamp. All have their place, however, as there is admittedly a field suitable for each, and without entering into a discussion as to their relative merits, we may content ourselves with stating that the selection of the lamp depends entirely upon the nature of the work to be carried out.

The flame arc is undoubtedly one of the most efficient of arc lamps, and compares very favourably, as far as efficiency is concerned, with the half watt lamp. It must be remembered, however, that a true comparison cannot be expressed in cost per candle-power, since factors like convenience cannot be directly expressed in figures.

As a general rule, it may be stated that for large rooms with high ceilings, high power units such as half watt lamps, luminous and flame arcs, or mercury vapour lamps, should be employed, while for average factory practice the incandescent electric lamp is to be recommended, the size of the unit depending upon the conditions, and preference being given to the largest unit which will enable the desired illumination to be obtained. Colour considerations apart, the mercury vapour lamp is finding great favour in modern automobile factories, and special cases of its application will be instanced in a later part of this work.

COMPARISONS BETWEEN HALF WATT TYPE LAMPS AND ARC LAMPS OF VARIOUS PATTERNS.

Enclosed arc lamps have been, and still are, extensively used in the lighting of large working areas, the comparatively long burning hours of the carbons being one of the chief points in the favour of the lamps. The efficiency is, however, very low, and half watt lamps are unquestionably superior in all respects. The following figures, obtained by Professor J. T. Morriss, M.I.E.E., during the test of such a lamp, are instructive in this connection :

Mean Watts.	Max. C.P.	M.H.S.C.P.	Watts per M.H.S.C.P.
465 ..	570 ..	340 ..	1.37

A polar curve of the light distribution is afforded in fig. 1, as well as that of a Mazda 500 watt half watt lamp equipped with an enamel reflector and Alabas globe. A characteristic light distribution curve of the half watt lamp is also given in fig. 2.

The figures for the 500 watt metal lamp prove that the half watt equipment is 50% more efficient than the enclosed arc lamp, the result of tests on both a 500 and 300 watt lamp being as follow :

Mean Watts.	Max. C.P.	M.H.S.C.P.	Watts per M.H.S.C.P.
500	972	779	.64
300	480	417	.72

A comparison of the operating and maintenance costs for 1,000 hours is also instructive, energy being rated at 3d. per unit :

Comparative Operating and Maintenance Costs.

Enclosed Arc Lamp.		Half Watt Type Lamp, with "Alabas" Globe.		
	465 Watt. Lamp.		300 Watt. Lamp.	500 Watt. Lamp.
	£ s. d.		£ s. d.	£ s. d.
Cost of current .	5 16 3	Cost of current .	3 15 0	6 5 0
Carbons . ..	3 0	Renewals (lamp)	1 5 0	1 10 0
Trimming and cleaning ..	3 0	Cleaning ..	1 0	1 0
Interest on lamp (5%)	3 0	Interest on fitting (5%) ..	2 7	2 7
Depreciation on lamp (10%) .	6 0	Depreciation on fitting (10%) .	5 2	5 2
	£6 11 3		£5 8 9	£8 3 9
Cost per c.-p. hour . ..	d. .00463	Cost per c.-p. hour.. ..	d. .00313	d. .00252

The overall saving on the assumed basis is, therefore, 45.5% in favour of the 500 watt half watt lamp, and 32.5% in favour of the 300 watt half watt lamp.

Comparison with the open type of arc lamp, which has been, and is, largely used for the lighting of open spaces, goods yards, etc., is just as favourable to the half watt lamp, the latter proving itself on test to be over 40% more efficient than the arc.

In addition, numerous other advantages are to be gained by the substitution of the half watt lamp for the arc. Thus trimming, adjustment, and attention may be dispensed with, a very desirable condition wherever labour is scarce and positions are inaccessible. A non-flickering, steady light is also assured, a very essential feature in all work where a constant demand is made on the eyes of the worker.

With flame arcs the comparison is still in favour of the half watt lamp as far as the cost per candle-power hour is concerned, although the metal lamp is theoretically not so efficient as the arc. The former gains, however, by reason of its simplicity and adaptability, the colour of the light emitted being also in its favour. A further great point is the number of sizes available, permitting of the use of the correct size of lamp for each location, whereas the flame arc can only be used economically where a great suspension height is available, otherwise the extra efficiency is largely wasted.

THE OPPORTUNITY TO OVERHAUL WORKS LIGHTING EQUIPMENT.

Stress has been laid on the advent of the half watt lamp and its very economical employment in conjunction with scientific and correctly designed reflectors in order to bring home to the works manager the necessity for immediately considering the lighting of his own works and the opportunities for improvement. It is true that artificial lighting is but seldom required during the summer months, the long hours of daylight sufficing for all ordinary work, with, of course, the exception of night work. In time of peace, however, prepare for war, and in view of the present difficulty in obtaining supplies and carrying out installation work, it would be well if all winter lighting requirements were carefully considered and planned out during the summer months. In this way the manufacturers of reflectors would have time to consider each case on its merits, and the works manager would be assured of a sufficiency of correctly directed light during the winter months.

CHAPTER VI.

ILLUMINATION AND ITS MEASUREMENT.

IN Chapter II. mention was made of the unit of illumination—the foot-candle—and a formula was given to enable the illumination at any point on the working area to be determined. No details were afforded, however, and in view of the tendency of reflector manufacturers towards the scientific treatment of their products, a brief discussion of illumination and its measurement is now essential. Mean horizontal and mean spherical candle-power, for example, are terms in common use. Lamps are rated in "lumens," while utilisation constants, etc., are freely discussed, from which it will be gathered that a clear understanding of the expressions in use is necessary if progress is to be made in the right direction.

In general terms, it may be stated that whenever light falls upon a surface the surface is said to be illuminated, the illumination depending solely upon the quantity of light incident on the surface, and in no way upon the physical characteristics and reflecting properties of the latter. The colour scheme, it is important to note, has no influence upon the illumination, although the colour of the decorations largely controls the results. Thus, adjacent surfaces of white paper and black velvet may receive equal illumination.

The white paper, having a high coefficient of reflection, will reflect the greater portion of the light falling upon it, and in consequence appear well lighted, whereas the velvet will absorb practically the whole of the incident light, which is thus wasted and merely raises the temperature of the material.

Illumination is thus seen to refer simply to quantity of light, and great care must be taken to ensure that the term always has its correct meaning assigned to it.

CANDLE-POWER.

The accurate measurement of illumination necessitates a knowledge of both candle-power and the unit of distance employed. Candle-power is measured simply as an intensity in any direction, and the expression signifies the unit of luminous intensity. As the name implies, the term was originally

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derived from the luminous intensity of the candle flame, but, since repeated research has demonstrated the fact that so-called standard candles do not yield a flame of unvarying intensity, the candle is now no longer regarded as an accurate standard.

INTERNATIONAL CANDLE.

Measurement of candle-power is not made directly, but by comparison with standards of known candle-power kept in the National Laboratories of Great Britain, France, and the United States. The unit that has been adopted by the latter countries as the International unit of candle-power is called the International Candle. Such a candle is defined as being equal to one pentane candle, or one-tenth of the British standard, the Vernon Harcourt 10 candle-power pentane lamp. The Hefner is the unit of luminous intensity in use in Germany, and denotes the standard intensity of the Hefner lamp. Since it is the practice of German and other Continental manufacturers to rate their products in terms of the Hefner unit, the relative values of the standards should not be lost sight of. Thus a 16 candle-power lamp (Hefner) would only be rated at 14.4 candle-power (British), with a corresponding increase in the watts per candle—the power absorbed by a lamp in watts, it might be here noted, being determined by the product of the current in ampères and the pressure in volts. In efficiency comparisons it is, then, always advisable to ascertain the unit of luminous intensity employed in each particular case before proceeding to conclusions.

MEAN HORIZONTAL CANDLE-POWER.

Candle-power, as previously mentioned, signifies an intensity in one direction only, and, since the candle-power usually varies with the direction, it has become customary to rate a lamp in terms of the mean horizontal candle-power (M.H.C.P.) with clear bulb and without reflectors. The mean horizontal candle-power is the average candle-power in a horizontal plane passing through the luminous centre of the lamp. The value may be determined by taking the average of a considerable number of measurements in the horizontal plane mentioned, but the more usual method is to rotate the lamp at 180 revolutions per minute about a vertical axis. By this means every view of the filament is presented in turn to the photometer screen and the average intensity thus computed.

MEAN SPHERICAL CANDLE-POWER.

The horizontal candle-power measurement was adopted simply because it was the customary and most convenient method of measuring the intensity of gas, oil, and candle flames, sources which generally burn in a vertical position. Incandescent vacuum lamps, however, may be used in any position, and it is also possible to effect a considerable variation in the light distribution by the simple process of changing the shape of the filament.

As horizontal candle-power measurements disregard all light emitted save that in a horizontal direction, and as light sources yielding widely different total amounts of light may emit the same amount of light in a horizontal direction, it follows that the horizontal determination of candle-power does not yield complete data, especially when lamps with varying types of filament are being employed. Further, with any type of lamp the intensity varies with the direction, and is, moreover, modified by the use of globes and reflectors ; from which it follows that a candle-power rating has no value unless the equipment used and the candle-power referred to are fully described.

A full and complete measurement of candle-power requires that consideration should be given to the light emitted in all directions. If we imagine the lamp to be surrounded by a sphere and the candle-power to be measured in the direction of radii to all points on the surface of the sphere, the average of the intensities so found takes account of the light emitted in all directions, and is known as the mean spherical candle-power (M.S.C.P.) of the source. The mean spherical candle-power may be considered as a measure of the total flux of light. Thus, imagine a luminous source radiating flux with unit intensity in all directions. From the source unit flux will be given out within each unit solid angle, the total luminous flux being equal to that within each unit solid angle multiplied by the number of such angles about the source.

THE LUMEN.

The unit of luminous flux defined above is known as the Lumen, and is analogous to the terms horse-power and watts, used in mechanical and electrical engineering. The total lumens emitted by unit source clearly equal 4π, and by any source $4\pi \times$ M.S.C.P., or 12.57 multiplied by the mean spherical candle-power of the source. The lumens emitted in either hemisphere equal $2\pi \times$ M.U.S.C.P., or $2\pi \times$ M.L.S.C.P. —that is, 6.28 multiplied by the mean upper or mean lower spherical candle-power respectively.

The complete determination of the spherical candle-power of incandescent lamps involves considerable work with special apparatus, but it is possible, however, to determine approximately the M.S.C.P. from a knowledge of the more readily determined M.H.C.P. and the spherical reduction factor.

MEAN SPHERICAL REDUCTION FACTOR.

The spherical reduction factor of a lamp is the ratio of its mean spherical to its mean horizontal candle-power, or

$$\text{mean spherical reduction factor} = \frac{\text{mean spherical candle-power}}{\text{mean horizontal candle-power}}$$

Example.—The M.S.C.P. of a lamp whose M.H.C.P. is 32 and spherical reduction factor .8 is equal to $32 \times .8 = 25.6$ M.S.C.P.

EFFICIENCY OF LIGHT SOURCES.

Efficiency is expressed in terms of specific consumption or specific output, as watts per M.S.C.P., lumens per watt, lumens per cubic foot of gas, etc., and is a very important feature of a lamp, as it measures the temperature of, or strain upon, the filament while burning. Consequently a change in efficiency very materially affects a lamp's life and candle-power performance.

As previously stated, the efficiency of a lamp is usually expressed in terms of the M.H.C.P., but this basis of comparison is correct only for lamps having the same shaped filaments with identical reduction factors. The spherical efficiency, or watts per M.S.C.P., is a correct basis of comparison for all lamps of the same filament material irrespective of the shape of the filament. However, the efficiency usually employed in the case of standard vacuum lamps is the mean horizontal candle-power efficiency, and when mean spherical candle-power efficiency is understood such is specially stated. As the candle-power and consumption of a lamp change during its life, it is obvious that the average efficiency varies from the initial or starting efficiency. The efficiency as practically employed is always the initial efficiency unless otherwise stated.

In Table IV. the efficiency of various lamps on an equal basis of mean spherical candle-power is afforded.

TABLE IV.

COMPARATIVE EFFICIENCIES OF VARIOUS ELECTRIC LAMPS.

Description of Lamp.	M.S.C.P.	Watts per M.S.C.P.	M.S.C.P. per Kilowatt
Common, 56 watt, carbon filament glow lamp, rated at 3.5 w.p.c., 16 horizontal candle-power	13.2	4.24	236
Tantalum, metal filament lamp (40 watt)	16.4	2.44	409
Continuous current 5 ampère enclosed arc, on 100 volt circuit	228	2.45	407
Alternating current enclosed 6 ampère arc, taking 388 watt, 110 volt	156	2.62	402
60 watt, 110 volt Mazda lamp, 1.1 watt per M.H.C.P. ..	42.5	1.41	708
1,000 watt, 110 volt, Mazda half watt type lamp	1340	.75	1340

UNIT OF ILLUMINATION.

The term candle-power having been completely defined, it is now possible to proceed to a definition of the unit employed in illumination measurements.

The unit in general use is the foot-candle, and, as previously stated, is defined as the illumination produced by a source of one candle-power on a surface everywhere one foot distance from the source. The foot-candle is also defined as an illumination of one lumen per square foot, from which the lumen may be further defined as the flux of light which produces an average illumination of one foot-candle over one square foot. Consider a point source of unit intensity placed at the centre of a hollow sphere of one foot radius. The total flux emitted will be intercepted by the surface of the sphere, and the flux incident on each square foot of the surface will be given by :

$$\frac{\text{Flux}}{\text{Area}} = \frac{4\pi}{4\pi} = 1 \text{ lumen per square foot.}$$

Since the flux is 4π lumens and the area 4π square feet.

According to the first definition of the illumination unit, it is clear that the illumination at all points on the surface of the sphere is the same, and equal to one foot-candle, all points being the same distance—one foot—from the source of one candle-power, while from the above calculation it is obvious that to produce an illumination of one foot-candle the flux incident upon each square foot must be one lumen.

Law of Inverse Squares.

If the above source is now placed at the centre of a sphere of two feet radius, the new surface will in its turn intercept the total flux emitted, but, since the area of the surface of the sphere has increased four times, it follows that the light incident upon each square foot will be only one-fourth of what it was in the previous case. In other words, the illumination will only be .25 foot-candles, from which it follows that the normal illumination is inversely proportional to the square of the distance of the surface from the source. Further, since the illumination at a point is clearly directly proportional to the intensity of the source in the direction of the point, it follows that the normal illumination at the point is given by $\frac{CP}{D^2}$ foot-candles, where CP is the candle-power and D the distance in feet of the point from the source.

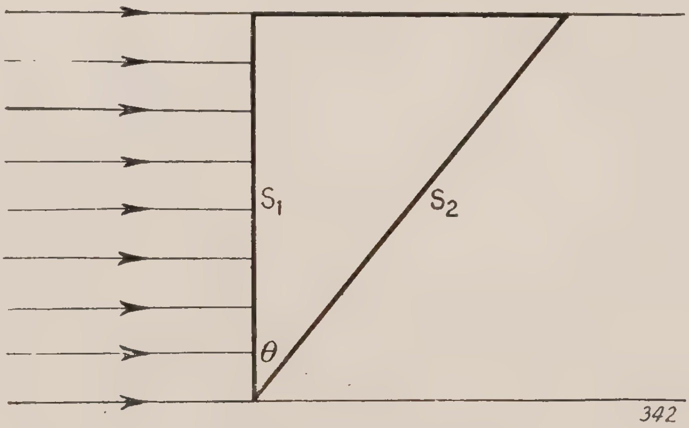

Fig. 1.—Illustrating the cosine law.

This rule, which is known as the Law of Inverse Squares, does not apply in the above simple state if the light falls obliquely on the surface under consideration, nor if the ratio of the size of the light source to the distance of the source from the point considered is not small enough for the source to be considered as a point. The law, further, does not apply to a plane source, such as a diffusing ceiling or to a line source such as a Moore tube.

Law of Cosines.

In practice the majority of the light rays do not meet the surface normally, or, in other words, the surface will be found to be inclined to the direction of the rays of light. In fig. 1 the screen S_1 of area A is shown intercepting the parallel beam of light indicated by the arrow heads. If Q is the flux incident on S_1, the normal illumination will be given by $E_1 = \frac{Q}{A}$. Let S_1 be now removed and its place taken by S_2. The same flux Q will in its turn be intercepted by S_2, but, since the area of S_2 is greater than that of S_1, the illumination will be decreased, and will equal :

$$\begin{aligned} E_2 &= \frac{Q}{S_2} \\ &= \frac{\frac{Q}{A}}{\cos\theta} \\ &= \frac{Q}{A}\cos\theta \\ &= E_1\cos\theta \end{aligned}$$

The angle θ is clearly equal to the angle of incidence, or the angle made between any ray and the normal to the surface at the point of incidence, from which it follows that the illumination decreases as the cosine of the angle of incidence.

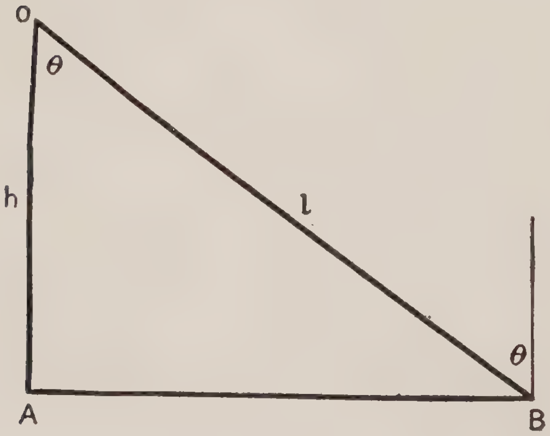

FIG. 2.

From the result obtained, which is known as the Cosine Law, and the Law of Inverse Squares, the illumination at any point may be expressed in terms of the intensity of the source in the direction of the point, the distance between the point and the source and the angle of incidence θ. Thus the illumination

$$E = \frac{CP}{D^2}\cos\theta$$

where CP is the candle-power in the required direction, D the distance in feet between the point and the source, and θ the angle of incidence.

In fig. 2 O is a point source of candle-power CP, and is suspended at a height h above the working plane. Also B is the point at which the illumination is required, and l its distance from the source.

From the above laws the illumination at B in the plane AB is equal to $\frac{\text{CP}}{l^2} \cos \theta$.

But $l = \frac{h}{\cos \theta}$, whence the illumination $= \frac{\text{CP}}{h^2} \cos^3 \theta$, and varies as the cube of the cosine of the angle of incidence for a given candle-power and height of lamp. The latter equation is known as Lambert's Law, and is of great importance in all illumination calculations.

FLUX OF LIGHT METHOD OF CALCULATING ILLUMINATION ON A HORIZONTAL PLANE.

While the "point by point" method of calculating the illumination on a horizontal plane is fundamental, and must always be used for calculations involving equipment whose characteristics have not been fully determined, it is too cumbersome a method for general use, and more convenient formulæ are essential.

The lumen has already been defined as the quantity of light necessary to produce an average illumination of one foot-candle over one square foot. The intensities of illumination necessary for various classes of lighting service have also been accurately determined by numerous observations and practical tests (Chapter II., Table I.), and, since the area of the working plane is readily ascertainable, the effective lumens on the working plane may be at once determined. This is the basis of the most convenient and correct method of planning lighting installations, since, if the lumens actually required are known, and the utilisation constants of the equipment are at hand, the total lumens required may be readily found. It is then a simple matter to fix the size and number of the lamps required.

INTENSITY REQUIRED.

The intensities necessary for satisfactory factory service, as before stated, have already been indicated, and, although it is a matter of experience before exact figures can be predicted, extreme limits may be decided upon with more or less accuracy, since it will be obvious that the intensity should never be so low as to be the contributory cause of accidents. Bearing this point in mind, a lower unit may be fixed according to circumstances, a value of .25 foot-candles having frequently been suggested. The upper limit is somewhat more difficult to determine, and the class of work must be taken as the deciding factor. Rapidly moving machinery and fine detail work on dark objects have been known to demand an intensity of as high a value as 50 foot-candles. This is, however, an extreme figure, and the usual practice is to set the upper limit at 10 foot-candles or thereabouts.

DETERMINATION OF THE TOTAL QUANTITY OF LIGHT REQUIRED.

Having finally decided upon the correct intensity, the next step is to determine the total quantity of light required.

Consider again the definition of the lumen. It will be recalled that this unit has been defined as the quantity of light necessary to produce an average illumination of one foot-candle over an area of one square foot. The lumens necessary on the working plane will then clearly equal the number of square feet in the room multiplied by the average intensity in foot-candles as already determined.

TABLE V.

UTILISATION FACTORS (BREWSTER).

Reflector.	Range of Factor.
DIRECT LIGHTING :	
Prismatic Glass	40–60%
Steel { Dome shape	55–65%
Steel { Bowl shape	45–55%
Opal Glass	30–50%
SEMI-INDIRECT LIGHTING	30–42%
INDIRECT LIGHTING	30–40%

So far the problem is a perfectly simple one, but it is unfortunately complicated somewhat through part of the light emitted by the lamps being absorbed by the ceiling, walls, and lighting equipment. An inspection of the distribution curve of any lamp, or of a lamp and reflector combination, will make it apparent that the whole of the light flux does not reach the working plane. In the case of a bare lamp approximately one-half of the total light is emitted in an upward direction (fig. 2, Chapter V.), and to reach the working plane must be reflected from the ceiling and upper portions of the surrounding walls. Such reflection is always accompanied by loss of light, since there is no perfect reflecting surface, and even in the case of an opaque reflector of the concentrating pattern, where the whole of the light is apparently directed downwards,

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calculation and reasoning show that this is not equal to the total flux generated, since the reflector itself absorbs light. The loss may be calculated by actual measurement with typical equipment, and Table V. affords utilisation constants for the material usually met with in practice.

In using the table, for example, in the case of industrial bowl-shaped metal reflectors it will be noted that from 45-55% of the light generated is usefully employed.

The necessary factor having been selected, the total lumens required may then be determined by dividing the number of effective lumens, as ascertained above, by the utilisation constant. A simple formula is thus arrived at, and the total light in lumens may be expressed as follows:

$$\text{Total light in lumens} = \frac{\text{Intensity in foot-candles} \times \text{Area in sq. ft.}}{\text{Utilisation factor}}$$

The Choice of Reflector.

Since the utilisation factor requires a knowledge of the type of reflector to be employed, the latter must be known before the calculations may be proceeded with. The class of service as a rule is sufficient to determine the reflector which will give the greatest satisfaction, but in case any doubt may exist in this connection it might be well briefly to discuss the reasons underlying the choice of a suitable reflector.

The three systems of supplying illumination to the working plane are known respectively as the direct, semi-indirect, and totally indirect systems, and, while all three are applicable to interior lighting, each has its limitations, advantages, and disadvantages.

In direct lighting the light from the lamp is projected directly on to the surface requiring illumination, without the necessity arising for employing the ceiling or walls as reflecting surfaces. Ordinarily direct lighting obtains when at least one-half of the emitted light is projected downwards or to the side, and bare lamps, clear or frosted lamps enclosed in spheres, lamps provided with translucent or opaque reflectors so arranged as to direct the light downwards, etc., are included in this classification.

Semi-Indirect Lighting.

In all semi-indirect installations a diffusing or translucent medium is employed with the object of directing the major portion of the light on to the ceiling or reflector, there to be redirected in all useful directions. With all semi-indirect reflectors a portion of the light is also transmitted through the glass, the bowl thus becoming luminous and preferably of a surface brightness not exceeding that of the main reflector itself.

INDIRECT LIGHTING.

When the whole of the light emitted by the fixture is projected on to the walls and ceiling for redirection on to the objects below, the lighting is said to be indirect. Cove lighting and lighting by fixtures which totally conceal the light source by the interposition of an opaque reflector, are in this class. Indirect systems may be economically applied to rooms with light finishes, and, while the efficiency may be somewhat lower than with the direct system, it is possible to equal that of semi-indirect installations which do not transgress the lighting laws with respect to the degree of surface brightness of the reflector bowl. The efficiency is also considerably influenced by the size of the room, but, quite apart from efficiency, the system possesses marked advantages in the very even distribution obtained, the absence of glare, and the minimisation of shadows.

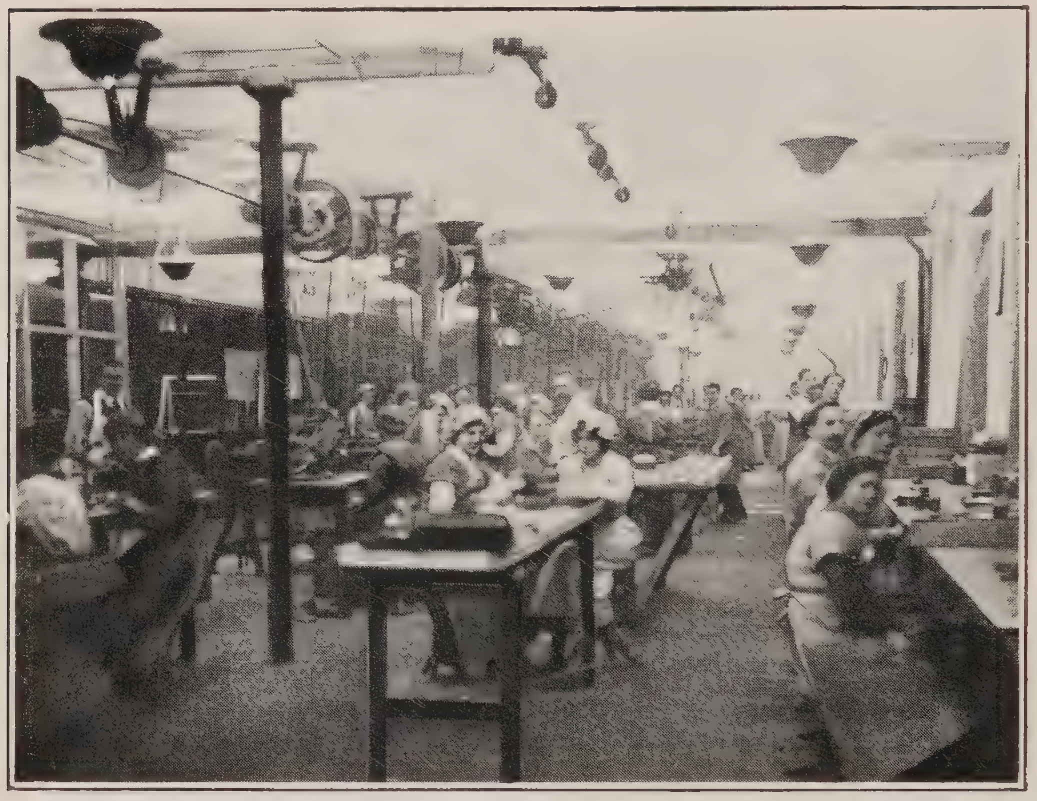

FIG. 3.—Indirect lighting in a munitions shop by the Wardle Engineering Co.

For factory lighting the direct system is generally to be preferred, since the efficiency is higher than in any other system, and the condition of the walls and ceilings usually leaves much to be desired. For such places as drawing offices, however, and for lighting polished surfaces (fig. 3), direct lighting is decidedly undesirable, and other instances will suggest themselves in which the elimination of shadows and glare will more than pay for the increased current consumption. In offices the freedom from eyestrain suggests the use of semi or totally indirect fittings, while in many such places it has been found preferable to install these fittings by reason of the fact that it is possible to locate the light sources irrespective of desk positions, and thus permit of a rearrangement of the office furniture without a corresponding rearrangement of the lighting units (figs. 4 and 5).

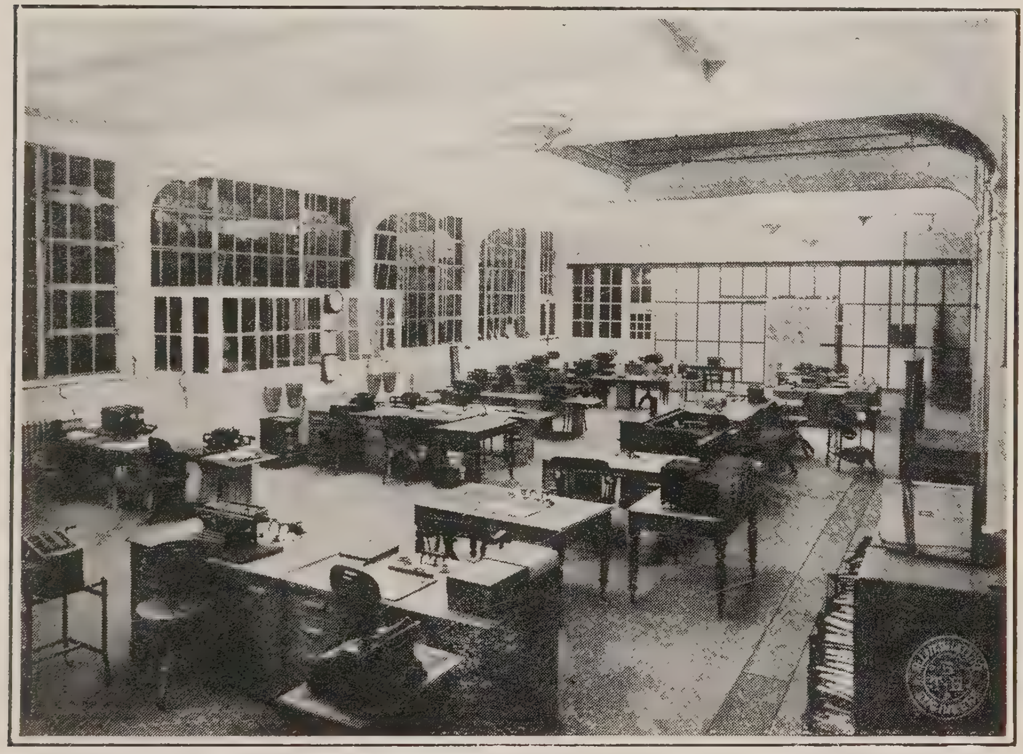

FIG. 4.—" Eye-rest " principle of indirect lighting applied to an office.

No very definite rules, however, can be laid down for determining the proper system, and one's judgment and experience must be relied upon in making the final decision, always bearing in mind the fact that it frequently pays to use a less efficient system in order to reduce shadows and eliminate glare.

SIZE, SPACING, AND SUSPENSION HEIGHT OF THE LIGHTING UNITS.

The area to be lighted should be divided as nearly as possible into squares and the light units placed at the centre of each square, since, in order to obtain good results from using the tables already given, it is necessary that the units should be spaced in fairly uniform rows. The size of the square depends to some extent upon the shadow effect desirable, and in general the smaller the squares the less intense the shadows. In large offices the squares should be comparatively small, in order to produce good diffusion, but in places where coarse work is undertaken the squares may be larger without any ill-effects resulting. Again, it may frequently happen that the exact size of square is determined by architectural considerations such as the size of bays, etc., when it may be necessary to use more than one light to the bay. At other times, owing to the design of the room, squares may not be permissible, when rectangles, as nearly square as possible, should be chosen.

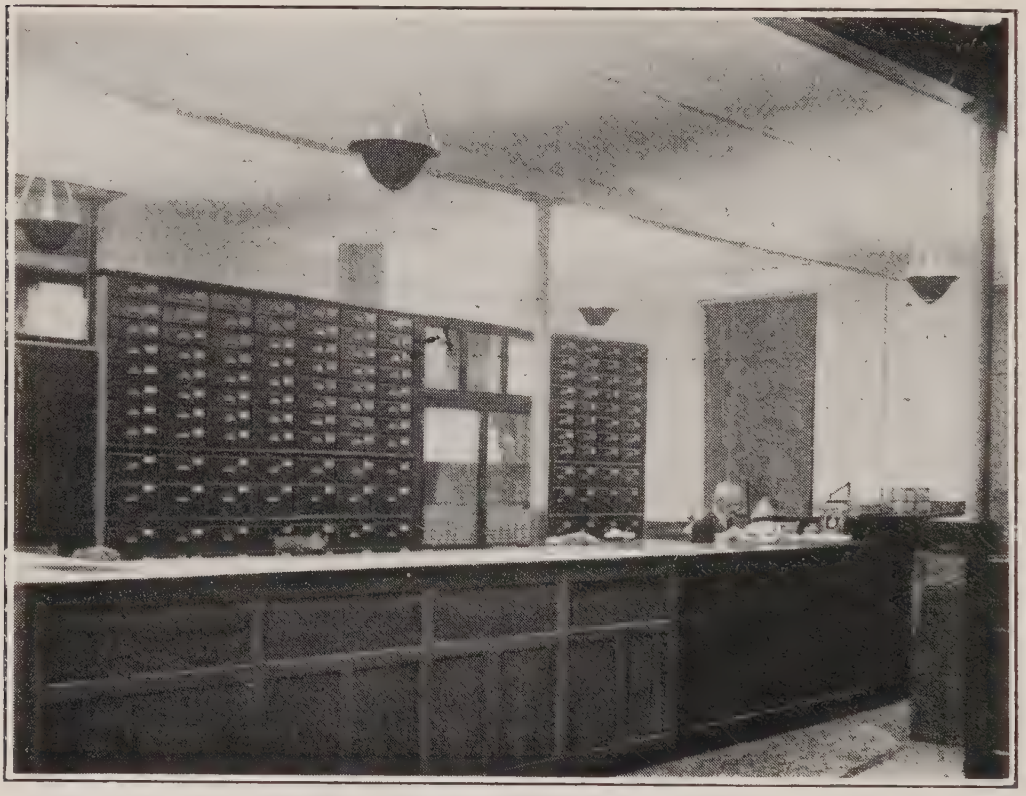

FIG. 5.—Indirect lighting in an office by the Wardle Engineering Co.

In all cases it must be remembered that the end in view is uniformity, or evenness of illumination, and that this end is only to be achieved by a correct spacing of the light units.

The necessary number of lamps being thus determined, their size follows from a knowledge of the total quantity of light required and that emitted by the various lamps at present on the market, for if the total lumens be divided by the number of lamps the size of the latter is at once determined by reference to Table VI :

TABLE VI.

TUNGSTEN DRAWN WIRE LAMPS.

	Size of Lamp in Watts.	Approximate Total Light Flux in Lumens.	
		100-120 volts.	200-260 volts.
A	20	163	147
	30	255	229
	40	341	330
	60	535	515
	100	930	905
B	200	2,795	2,500
	300	4,600	4,100
	500	8,060	7,400
	1,000	18,000	16,120

A. Vacuum type. B. Half-watt type.

TYPES OF REFLECTORS.

In selecting the reflector a knowledge of the spacing, or distance apart of the units, and the suspension height is necessary. The illumination intensity is determined by the size and number of the lamps employed, and is not governed in any way by the type of reflector, except, of course, in the case of single units lighting restricted areas. The higher the lamps are placed, provided that an efficient reflector is employed, the more nearly the conditions approach natural ones, and it is very important to understand clearly that placing the lamps well above the working plane does not indicate inefficient lighting. Generally speaking, lamps may be placed at any height above the working plane with equally efficient results, always provided that the correct reflectors, suitably disposed as far as spacing and height are concerned, are used.

Modern practice calls for three main types of reflectors, providing an extensive, intensive, or focussing distribution.

EXTENSIVE REFLECTORS are suitable for lighting long, narrow situations from a single row of units, and should be used in shops when it is desired to illuminate both benches and shelves from the same sources. Extensive reflectors may also be used with advantage for lighting large areas with low ceilings, and are designed to produce an even illumination when spaced a distance apart equal to twice their height above the working plane.

Intensive Reflectors are suitable for local and group lighting, and if the area to be lighted is small and requires a high intensity of illumination. The spacing ratio is 1.5, which means that an even illumination will be produced when the reflectors are placed a distance apart equal to 1½ times their height above the working plane (fig. 6).

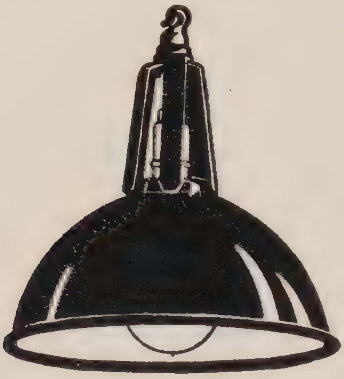

Fig. 6.—Intensive type "Workslite" reflector.

Focussing Reflectors are useful in offices and other places where high intensities are required, and are particularly suitable for local lighting of narrow strips from a single row and for general lighting of moderately lofty buildings. The spacing ratio is unity.

Concentrating Reflectors are necessary where the lamps have to be placed very high—above cranes, for example. The spacing ratio is .5.

Other reflectors, such as extra extensive and dispersive, are used when evenness of illumination is not of much importance or when the lamps must be hung low and spaced wide apart. The dispersive type provides a good vertical, as well as horizontal, illumination, and is exceedingly suitable for aeroplane construction works, railway platforms, and similar places.

CHAPTER VII.

MODERN PRACTICE IN ELECTRIC LIGHTING.

LIGHTING units may be arranged to provide localised or specific lighting, general lighting, combined local and general lighting, and localised general or group lighting. Local lighting is by far the simplest, and, to the average lay mind, the only method of utilising artificial light sources. Low candle-power incandescent lamps are usually employed and placed under the direct control of the operator, the effectiveness of the installation depending to a large extent upon the capability or otherwise of the latter. The lighting of an individual machine or operation may be carried out by local lighting, and the latter may also be employed for bench work, marking off tables, punching and drawing presses, and for any work necessitating light from a nearly horizontal direction or a high intensity over a small working area. Angle

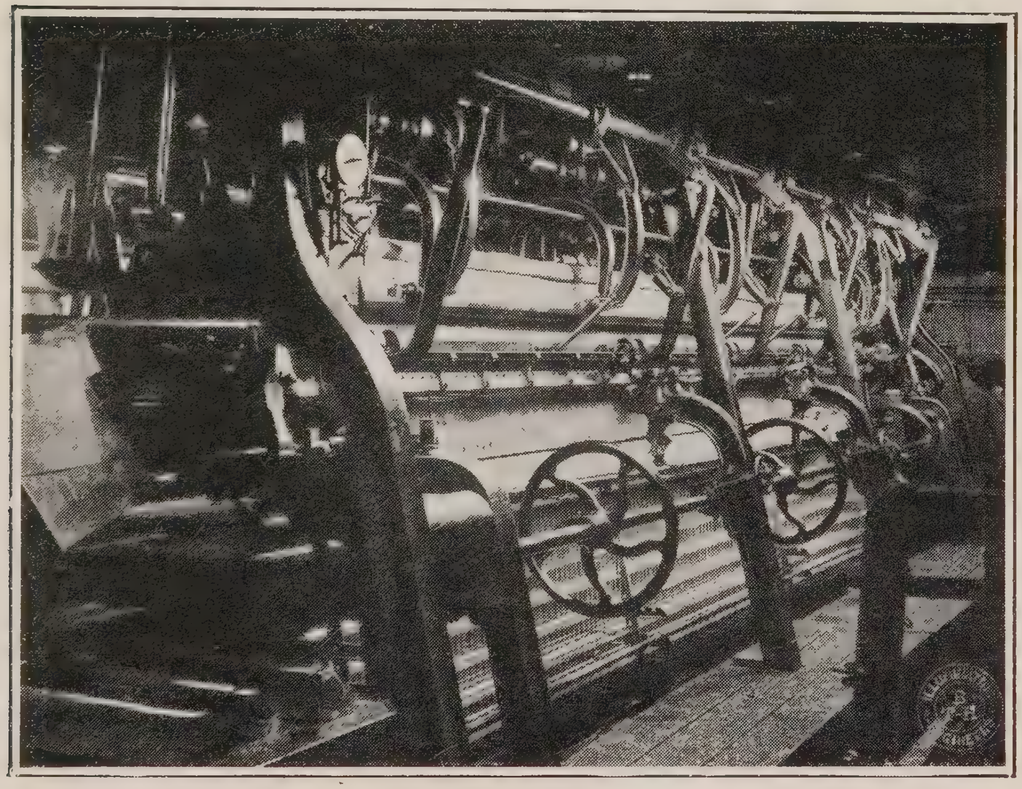

FIG. 1.—Correct local lighting.

type and focussing reflectors with small lamps are usually employed for local lighting, which, moreover, should always be supplemented with general lighting of a low intensity.

In local lighting it is possible to observe the light sources, but, although visible, the lamps should be so screened as to be out of the direct line of vision. The action of the eye should also be well appreciated before designing a local scheme, since the glare accompanying the contrast of a brilliant area adjacent to a dark background, and the reflection taking place from polished surfaces interfere with seeing, and, in addition to causing an annoyance, may, if encountered for a sufficient length of time, and in a high degree, result in serious injury. The eye is used to light from the sun—that is, to light from above—and the brows always serve as a protection to light from this direction. There is no corresponding protection provided, however, underneath, hence the eyes are more sensitive to strong light received from below, as in the case of snow blindness. Local lighting must then be very carefully arranged, and, except in special cases, has now been superseded by general or group lighting.

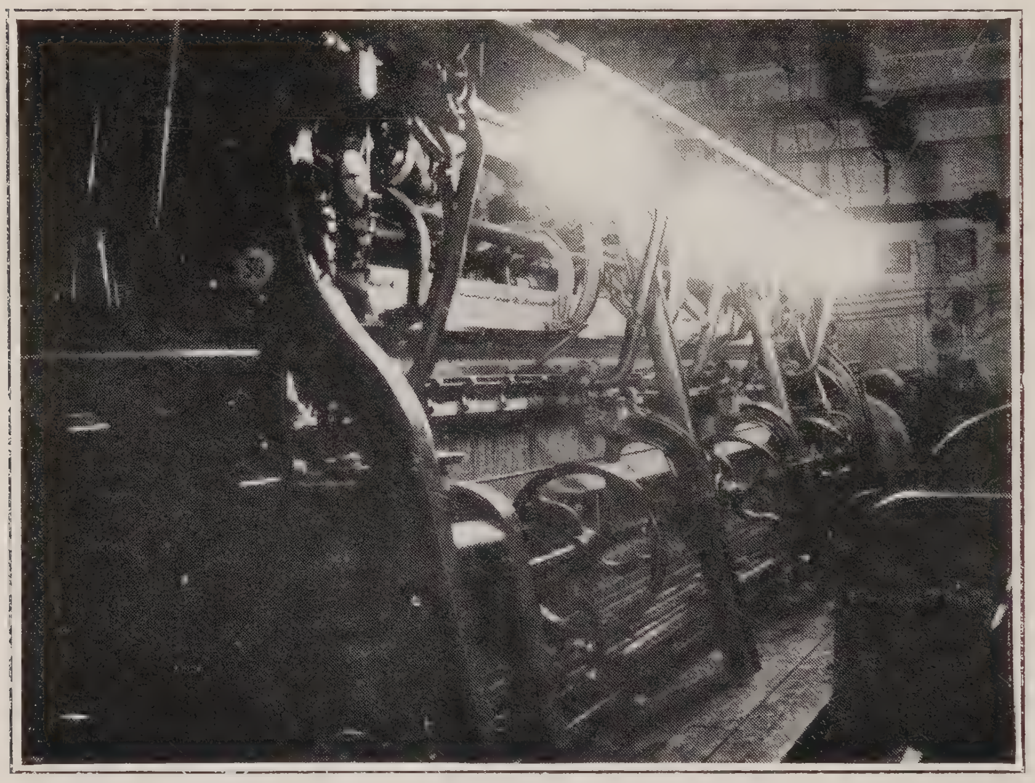

FIG. 2.—Faulty local lighting.

Figs. 1 and 2 provide examples of good and faulty local lighting, and from a study of the latter it will be evident that much harm may easily be the outcome of an inexperienced person interesting himself in lighting problems. In certain manufacturing processes local lighting is, of course, a necessity, since the machining, for example, of boiler and casting interiors could not possibly be undertaken by general room illumination. Local lighting is also useful for work inspection and, as mentioned above, for special bench and machine lighting. For economy in lighting small, widely separated areas local lighting is also to be advocated, but it must be remembered that any rearrangement of the processes will bring about a change in the wiring and increase the expense of the installation. Further, the initial cost of wiring a local scheme is likely to be high on account of the large number of points required, while the maintenance cost will be high by reason of the rough usage to which the lamps and reflectors are exposed.

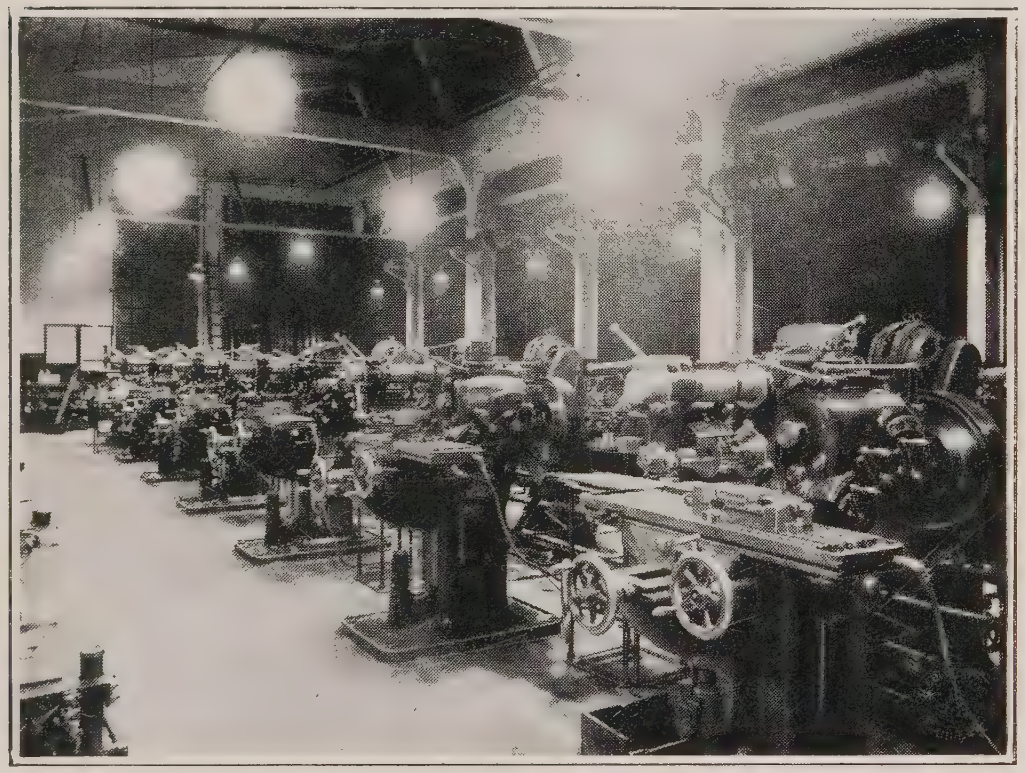

FIG. 3.—General lighting of a machine shop.

GENERAL LIGHTING.

In general lighting the room is lighted as a whole without reference to the work carried out in any particular part, and the majority of decorative and industrial lighting problems are solved by this method of installation. The lighting is thus quite independent of the furniture arrangements or processes in operation, and a reorganisation is possible without a corresponding change in the lighting fixtures. The ideal is seldom attained, but the result more nearly approaches daylight, or natural conditions, than with any other system of artificial lighting. A higher flux is usually demanded than with local lighting, but, on the other hand, the highest efficiency illuminants can be employed and the minimum installation and maintenance expense secured.

General lighting is particularly adapted for large, high, open workrooms where manufacturing is reasonably condensed and a large portion of the room requires illumination (fig. 3).

COMBINED GENERAL AND LOCALISED LIGHTING.

Local lighting with small lighting units arranged to provide a high intensity over a restricted area, supplemented with a low, general illumination by large lighting units, is suitable for a large room when small, isolated areas demand individual treatment. If the demand is a temporary one, local lighting by means of plugs and hand lamps can be arranged, but if otherwise a separate switch may be incorporated with each individual local light.

GROUP LIGHTING.

The advent of the high efficiency tungsten lamps has bridged the gap which formerly existed between the low candle-power incandescent lamp and the high candle-power arc lamp. With the range of sizes now available it is indeed possible to provide almost any required degree of intensity with any reasonable spacing of the units. As a result of this condition a practice of applying a general illumination, and known as group lighting, has recently been developed. Instead of trying to eliminate the variations in intensity an arrangement of lamps is adopted whereby the maximum illumination is received where it is most needed, while a lower intensity is available at intermediate or less important points. Group lighting is applicable to machine shops and similar places where the machines are arranged in rows, and embraces a wide range of practice from general lighting at the one extreme to local lighting at the other (fig. 4).

Example I.—As an example of the application of the above rules, the "Flux of Light" method will be applied in the design of a lighting system suitable for an automobile small part assembly room.

The room will be assumed to be 75ft. in length, 60ft. wide, and 12ft. high, with a dark ceiling and light walls.

Reference to page 30 will establish the fact that an average intensity of 4 foot-candles is desirable, from which the number of effective lumens required may be determined—effective lumens = 75 × 60 × 4 = 18,000 lumens.

For factory service opaque reflectors with a utilisation factor of .5 (Table V.) are to be preferred. The total lumens necessary are then found by dividing the effective lumens by the utilisation factor, and, performing the division :

$$\text{Total lumens} = \frac{\text{Effective lumens}}{\text{Constant}} = \frac{18{,}000}{.5} = 36{,}000 \text{ lumens.}$$

The height of the ceiling being 12ft., the side of the most convenient square lies between 8ft. and 12ft., and, choosing the lower limit, the number of lamps is found to equal 63.

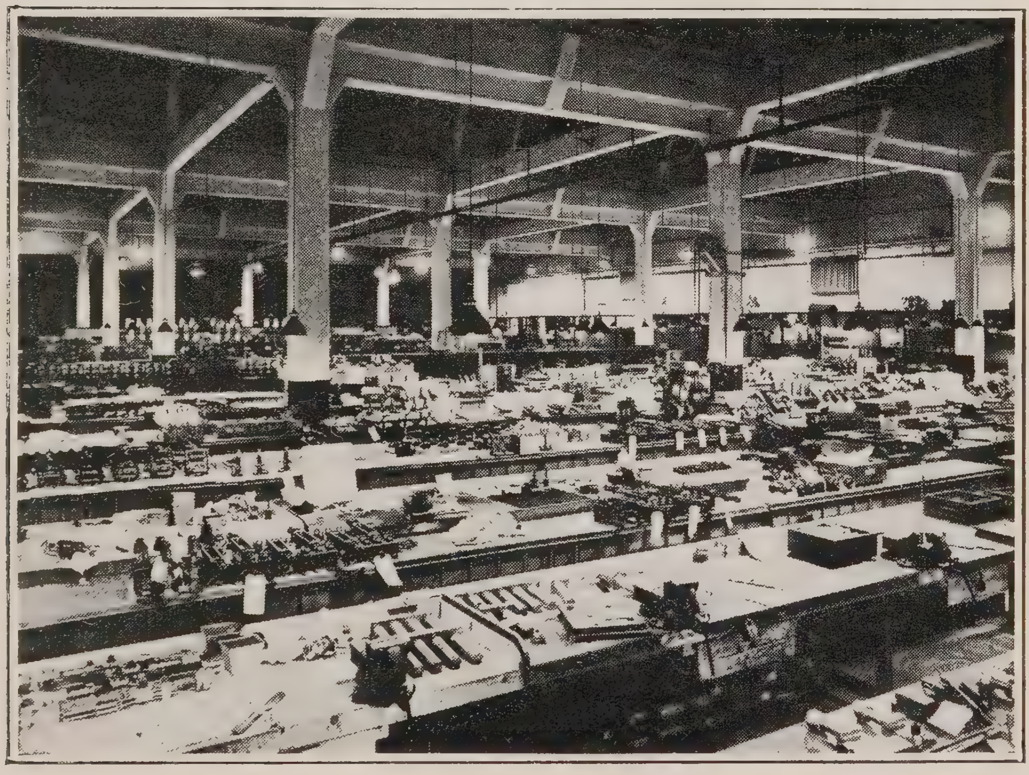

FIG. 4.—Group lighting of assembly benches. Mazdalux reflectors and Mazda lamps.

The size of the lamp may now be determined from a knowledge of the total lumens required and the number of units.

Thus, lumens per lamp $= \frac{36{,}000}{63} = 570$, and reference to Table VI. discloses the fact that 60 watt lamps are the nearest size. The suspension height above the working plane should be as great as possible to eliminate glare, and, since the ceiling is only 12ft. high, the units may quite conveniently be hung 1ft. 6in. below it. The spacing ratio will then be unity or focussing reflectors will be required, since the working plane is assumed to be 2ft. 6in. above the ground.

Example II.—As a further example, the installation for a main engineering shop 35ft. high will be considered. To clear the cranes it will be necessary for the reflectors, etc., to be placed close to the roof, say, 30ft. above the working plane, or, if cranes are absent, 20ft. will suffice. In the first case squares of 30ft. suggest themselves and focussing type reflectors, while in the latter case an intensive type of reflector (fig. 6, Chapter VI.) could be used and the spacing remain the same, the spacing ratio in the two cases being unity and 1.5 respectively. About 3.5 foot-candles will be adequate for this class of work, from which it follows that :

$$\text{Lumens necessary} = 30 \times 30 \times 3{\cdot}5 = 3{,}150$$

$$\text{Lumens generated} = \frac{30 \times 30 \times 3{\cdot}5}{{\cdot}5} = 6{,}300$$

assuming a utilisation factor of .5 for metal reflectors.

Five hundred watt half watt lamps will secure an even illumination of the necessary value, and afford an appreciable margin for deprecation due to dust collection.

APPLICATION OF THE FLUX OF LIGHT METHOD IN THE DESIGN OF SEMI AND TOTALLY INDIRECT LIGHTING SYSTEMS.

INDIRECT LIGHTING SYSTEMS.—In indirect lighting the whole of the light flux is thrown on to the ceiling, which thus becomes a secondary radiator. If free from glaze, no direct reflection is possible from such a surface, and the following inherent characteristics of indirect lighting result in the maximum of eye-comfort being attained :

Characteristics of Indirect Lighting.

(1.) Low surface brightness of the secondary radiator.
(2.) Well diffused light.
(3.) Marked uniformity of illumination.

The absence of glaring light sources in the line of vision permits of a large opening of the eye pupil, since the eye invariably adapts itself to the brightest object in the field of view. The muscles of the iris are also relaxed, and comfortable vision with the minimum of fatigue is assured (fig. 5).

Methods of Calculation.—In all indirect calculations it must be remembered that the ceiling becomes the secondary source of light, and in this capacity reflects and redirects the light flux generated by the lamps. Hence the ceiling should be an efficient reflector in order that maximum efficiency may be assured. A glossy finish, it should be noted, is as satisfactory as a matt finish from the standpoint of the reflecting efficiency and diffusion, but fails in respect of eye comfort. A blurred image of the lamp and reflector produces a decided glare, and it is therefore best to avoid the use of glossy finishes on ceilings that are to be used as reflecting surfaces in indirect lighting. Installations are usually classified according to the character of the work to be carried out. In offices and installations of the working type good uniformity and diffusion are essential, but slight shadows are not objectionable. In drawing offices, inspection rooms, gauge departments, etc., all shadows and shaded areas on the working plane must be eliminated. Whatever the nature of the work carried out, the procedure is much the same, and is similar to that already instanced for direct installations.

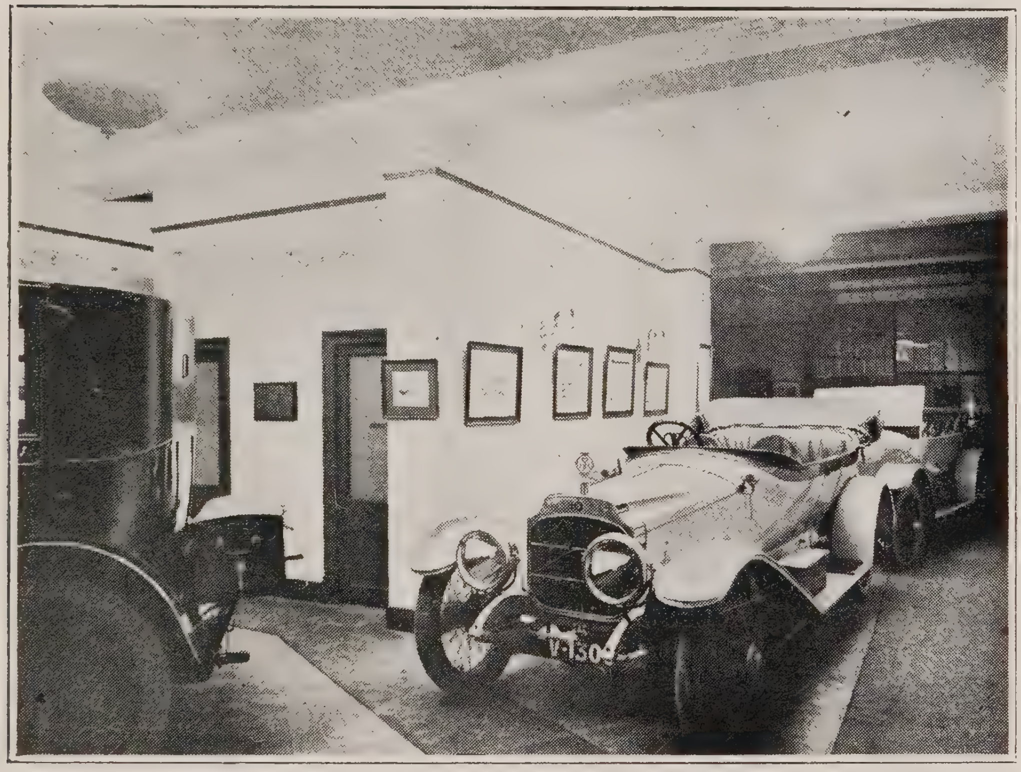

FIG. 5.—" Eye-rest " lighting in a motor showroom.

SEMI-INDIRECT INSTALLATIONS.—While approving of the underlying principles of indirect lighting, many people prefer a certain amount of direct light in addition to that obtained by diffused reflection from the ceiling, and to meet their requirements semi-indirect bowls in Opalba, Veluria, Sudan, and other ornamental and scientifically designed glassware have been designed.

In all semi-indirect installations a translucent reflector is used, and part of the light is transmitted directly through the bowl. The light source itself should never be visible, and the bowls should always be of sufficient density to ensure a low surface brightness only. In many such installations the bowl material is of too light a density, with the result that the direct component is predominant and the whole advantage of the system thereby destroyed. It must always be remembered that eye-comfort is the object in view, and that such is only to be obtained by the elimination of all glaring light sources from the line of vision. To shield the lamp and yet permit of a high value of bowl surface brightness is merely to substitute one glaring source for another, and the full advantages of semi-indirect lighting can only be secured by the employment of bowls of sufficient density to ensure an area of low surface brightness only being presented to the view. The main illumination should be obtained as in the indirect system—by diffused reflection from the ceiling or external reflector, and, provided that correctly designed bowls are employed, the rules instanced above may be applied in designing installations of this particular kind.

Industrial Lighting with Mercury Vapour Lamps.

The principle of the Cooper-Hewitt mercury vapour lamp is the incandescence of mercury vapour in a hermetically sealed glass tube, distinct types of lamps having been developed for direct and alternating current circuits. Mercury vapour lamps, on account of the peculiar bluish-green colour of the light and the tubular form of the light source, may be classified as strictly an industrial illuminant, and are a distinct advantage during protracted hours of night work when a soft, well diffused daylight effect is appreciated. The lamps have been adopted and their application thoroughly approved in steel works, foundries, machine shops, garages, mills, drawing offices, and printing rooms, and they readily lend themselves to the effective and efficient lighting of automobile factories. Among the advantages claimed by users and advocates are improved visual acuity, low intrinsic brilliancy, absence of glare, and good natural diffusion—characteristics which result in what may be termed a good seeing light being secured.

A typical lamp is shown in fig. 6, and an average life of 4,000 hours is claimed for the tube. The maintenance is thus practically reduced to a vanishing point, since only very occasional cleaning is required during the extended life of the tube. Breakage of the tube destroys the electrical circuit, hence fire risk does not exist, and, since the lamps may be made perfectly automatic, no attention to mechanism is required. The resulting illumination, when one has become accustomed to the somewhat weird effects of viewing objects under a blue-green light—red, for example, looks purplish-brown—leaves little to be desired. The light is steady, possesses superior penetrating powers, and shows up flaws in castings and machinery in a remarkable manner. It is further claimed that the consumption, .33 watt per candle, is superior to that of all other industrial illuminants, while the intrinsic brilliancy, or candle-power per square inch of the illuminated tube, is below that of all other artificial illuminants. The most rapid progress has been made in the States, where the first lamps were introduced as recently as 1903 in the composing room of the *New York Evening Post.* At the present time they are used in practically every industry, one metal working plant alone using over 2,500 tube lamps.

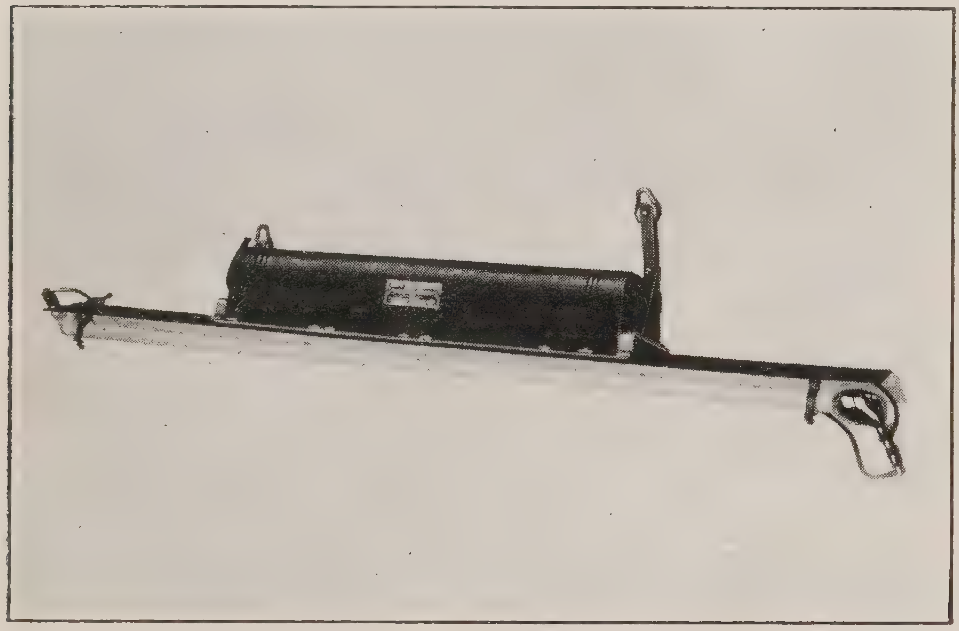

FIG. 6.—Mercury vapour lamp.

Other industries to which mercury vapour lamps have been proved to be specially applicable embrace metal working plants, foundries, forge and blacksmith shops, machine shops, varnish and finishing plants, and woodworking plants. Of special interest to automobile manufacturers is the lighting of foundries, machine shops, woodworking and varnishing and body finishing shops.

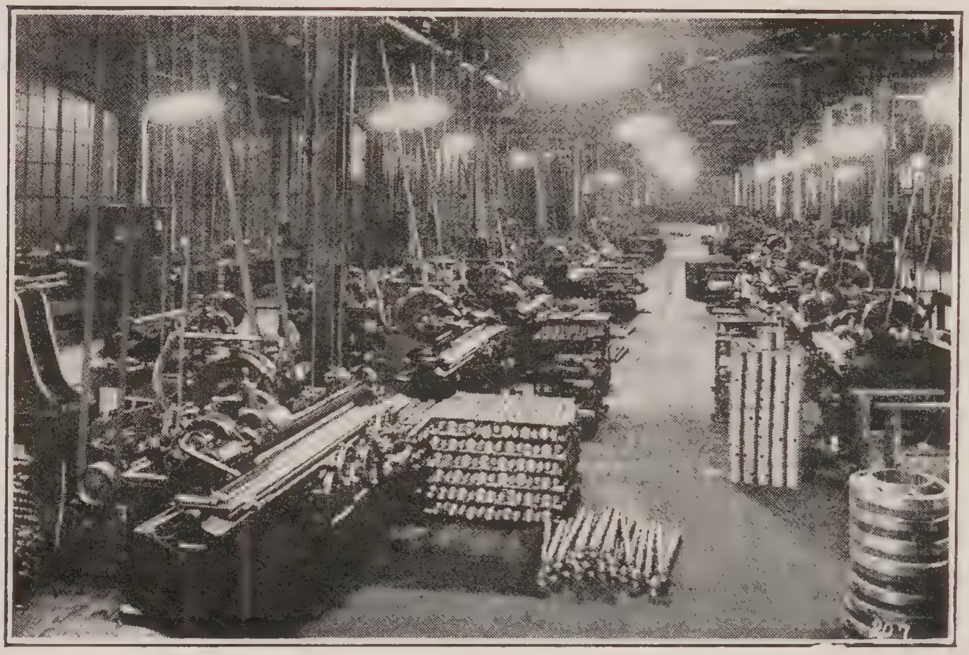

FIG. 7.—Mercury vapour installation in a machine shop.

FOUNDRIES.

The lighting of a foundry may roughly be divided into three parts—(1) moulding, embracing core making, (2) casting floor, and (3) the finishing operations, embracing chipping and cleaning. Most foundries are dark holes at night, and

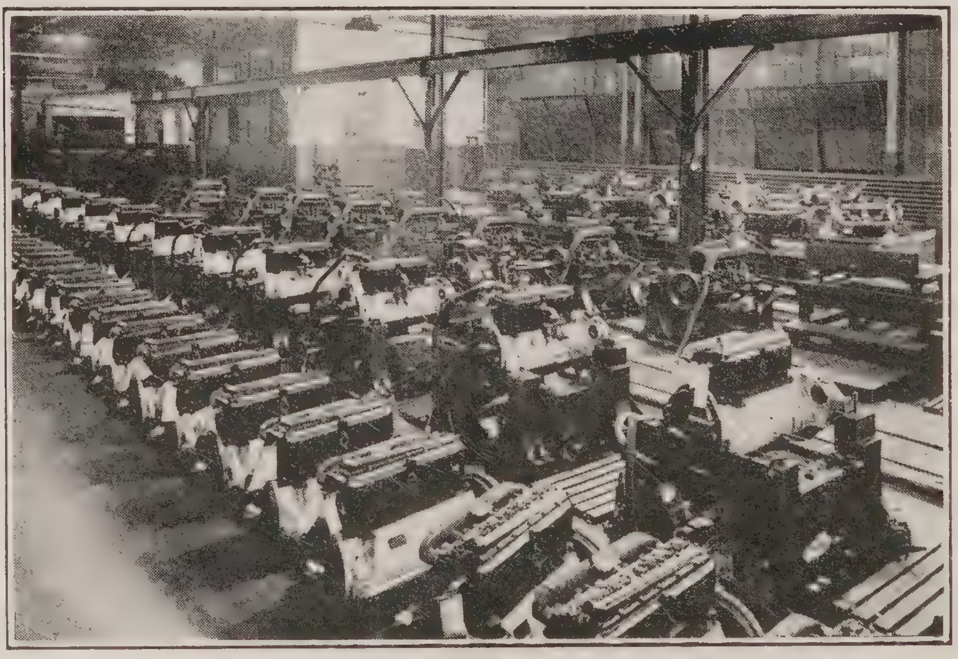

FIG. 8.—Engine assembly shop.

it should be borne in mind that accidents are of very frequent occurrence, and that too much light cannot be provided to guard against the dangers of workmen falling. In addition, lamps should be placed out of the field of vision as far as is practicable.

A few details of typical lighting with mercury vapour lamps are afforded:

MOULDING DEPARTMENT.

No.	Area, Square Feet.	Watts per Lamp.	Watts per Square Foot.	Height of Lamps above Floor in Feet.
1	6,680	725	·33	22
2	14,170	400	·27	15–27
3	22,225	400	·53	12
4	4,920	400	·31	15
5	83,500	200–400	·21	18
CASTING FLOOR.				
1	15,200	725	·52	22
2	12,400	725	·23	27
3	24,000	725	·24	45
4	28,180	725	·34	22
5	5,000	725	·29	42
CHIPPING AND CLEANING.				
1	25,500	400	·29	21
2	16,200	200	·33	13
3	4,400	200	·32	10

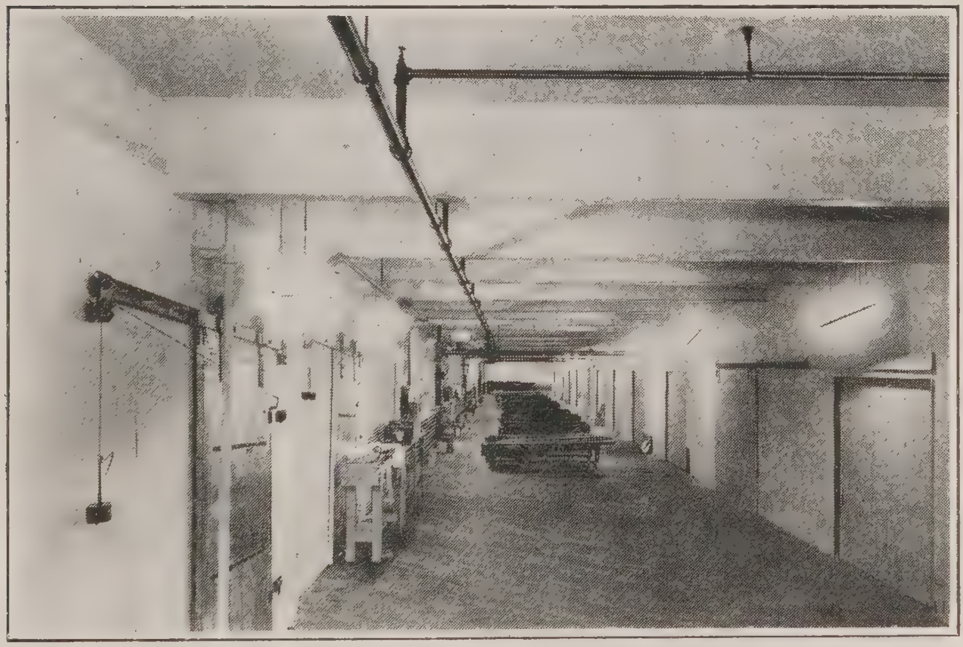

FIG. 9.—Painting by mercury vapour light.

MACHINE SHOPS.

In the following shops the lighting is entirely by mercury vapour lamps, and for boring, etc., individual local lights will be necessary, as previously explained:

No.	Work.	Area, sq. ft.	Watts per Lamp.	Watts per sq. ft.	Height in Feet.
1	Gear Cutting ..	22,800	400	.66	11
2	Auto. Parts (fig. 7, Chap. VII.)	25,240	400	.62	14
3	Auto. Engines ..	54,650	400	.52	13
4	Ball Bearings ..	5,840	400	.73	12
5	Revolver Parts ..	12,180	400	.75	10
6	Brakes	38,000	200–400	.6	14
7	Auto. Parts (Drills)	2,000	220	.65	12
8	Auto. Parts (Lathes)	12,000	400	.79	10
9	Engine Valves (Polishing)	1,280	200	1.2	12

ASSEMBLY AND ERECTING.

For the final operations the lighting is apt to vary widely, depending upon the nature of the product. Typical cases are afforded in figs. 7 and 8, in which two important departments are illustrated.

No.	Work.	Area, sq. ft.	Watts per Lamp.	Watts per sq. ft.	Height in Feet.
1	Assembling Motor Cars	6,192	200–400	.81	12
2	Erecting Cars ..	117,000	400	.3	20–29
3	,, ,, ..	24,000	400	.4	25–37

WOODWORKING PLANTS.

The lighting of woodworking plants is similar to that of machine shops, inasmuch as the machines must be adequately lighted to prevent accidents. It is found that the grain of the wood stands out particularly clearly under the green colour of the lamps.

No.	Work.	Area, sq. ft.	Watts per Lamp.	Watts per sq. ft.	Height.
1	Planing Mill (Car Parts) . . .	30,000	400	.28	20
2	Woodworking (Auto. Bodies)	7,700	200	.5	10

VARNISHING AND BODY FINISHING SHOPS.

Varnish shops require almost identical treatment to woodworking departments, and the painting and finishing of motor car bodies may also be included under the same head. Painting is of great importance, as the finish is the first point to strike the average purchaser. Painting is usually carried out in a long. narrow room with windows on one side and the dark rooms on the other. The room is kept closed throughout the process in order to keep out dust, etc., and the temperature

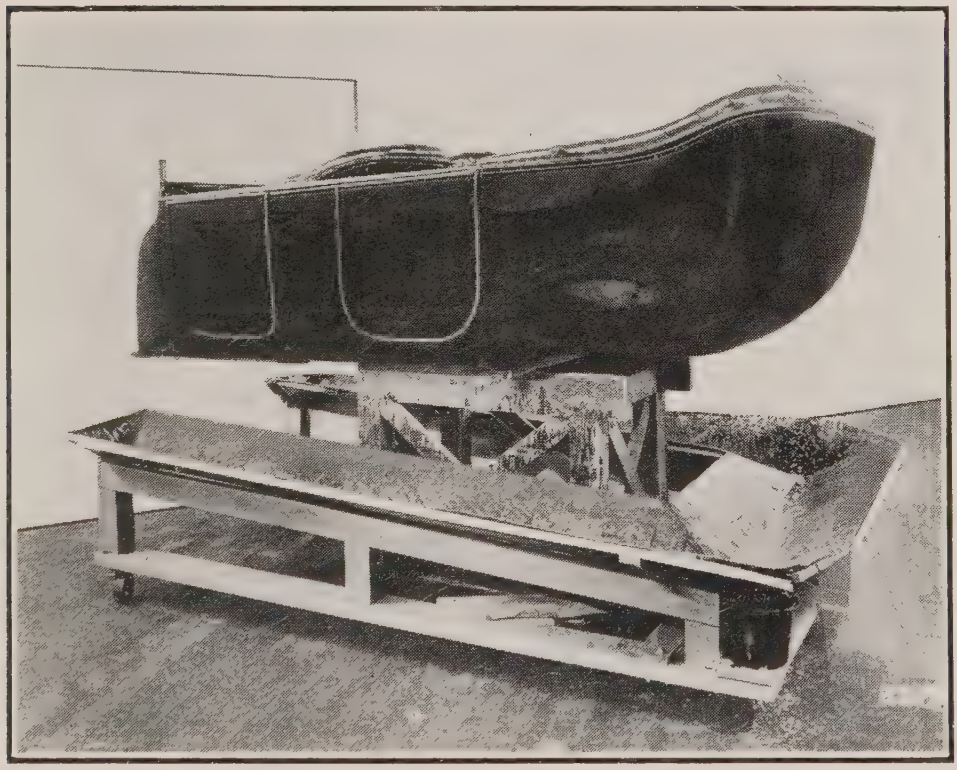

FIG. 10.—Mercury vapour lighting in motor body painting shop.

is maintained at a constant point. Two rows of mercury vapour lamps with angle reflectors throwing light on both sides of the body will permit of a rapid increase in output (figs. 9 and 10).

No.	Class of Work.	Area, sq. ft.	Watts per Lamp.	Watts per sq. ft.	Height.
1	Varnish Shop ..	37,500	200	.82	10
2	,, ,, ..	3,100	200	.75	10
3	Body Finishing .	4,400	400	2.28	8½
4	,, ,, ..	2,800	400	2.86	8½

CHAPTER VIII.

OIL LIGHTING.

ELECTRIC and, to some extent, gas lighting, may now be considered as standard for all modern industrial purposes, and from the previous chapters it will be clear that candle and oil lighting of the more elementary nature has been almost entirely eliminated.

Still, there are many occasions when it is impossible to install either gas or electric lighting. It frequently happens—for example, in remote country districts where it is expedient to erect a factory—that artificial lighting facilities are entirely non-existent. The heavy capital expenditure necessitated by the installation of an electric or gas lighting plant for an isolated works places such illuminants entirely out of the question. At other times, even when a supply of electricity or gas is available in the region of the works, the labour involved in arranging for an extension may be a sufficient reason for relying upon some other form of lighting agent. Many cases have recently arisen in which factories urgently required for Government work have been compelled to institute night-shifts and materially to increase their works output. The premises have been rapidly enlarged, with the result that the capacity of the lighting system has been considerably exceeded.

For all such cases incandescent oil lighting is specially suitable, while during the building period the extreme portability of the light units, permitting of their being swung from cranes, scaffold-poles, or derricks, makes for the maximum of economy and convenience to builders and contractors.

INCANDESCENT OIL LIGHTING.

The advent of the incandescent gas mantle entirely changed the aspect of gas lighting, and secured a great advance for the industry as a whole. It was natural that the application of the principle of incandescence to liquid fuels should be suggested thereby, and it was recognised that if a liquid illuminant could be vaporised and mixed with air in the correct proportions it might be utilised in the same way as the gas mixture, to raise an incandescent mantle to a high temperature and secure even better results than those obtained with ordinary town gas.

The question was investigated at length, and incandescent oil lighting was eventually invented in 1886 by Mr. Arthur Kitson. The first installation was carried out in the United States in 1894, a Kitson equipment being installed in a lighthouse on the Potomac River. Shortly afterwards the French, and still later the Trinity House authorities in this country, investigated the subject, and at present we understand that nearly every lighthouse on the British coast has a Kitson system installed.

Perhaps of more interest at the moment is the fact that the first factory equipment was also installed in the States, in Philadelphia, in 1896, since when many thousands of factories and works in all countries have followed suit and installed the Kitson light, it being estimated that there are in use at the present time upwards of three million incandescent oil lamps operating on this particular principle.

Principle of the Incandescent Oil Lamp.

Incandescent oil lamps are arranged to burn ordinary lamp oil without a wick, an incandescent mantle being used in its place.

By this means an enormous increase in the light output is secured, while at the same time a considerable decrease in oil consumption is effected.

The following figures relating to actual tests are of great interest in this connection.

A burner rated at three cubic feet of gas per hour gave, as the result of tests, a light of 12 candle-power. With an incandescent mantle and Bunsen burner 68 candle-power was secured with the same gas consumption, but with the same mantle an incandescent oil lamp rated at half a pint of oil per hour actually yielded 600 candle-power, an enormous increase with almost identical equipment.

Approximately the oil consumption of a Kitson 1,000 candle-power lamp is five-eighths of a pint per hour, and a room 30 × 60 feet may be well lighted by the use of one such unit.

Essential Features.

The essential elements are the lamp, the oil reservoir, and the necessary connecting tubing.

The reservoir is connected directly when the lamp is self-contained, or it may be connected by piping to the lamps, the latter system being employed when a number of light units are required, as in factory lighting.

The oil reservoir is of drawn seamless steel fitted with a gauge, to show the quantity of oil in the tank, a pressure gauge, and a check valve for automatically cutting off the supply in the event of damage occurring to the pipes. The Kitson factory lamp (J 12) is shown in fig. 1. This lamp is self-contained, and the reservoir with the gauges, etc., can be seen above the lamp.

The whole arrangement is wind and storm-proof, and may be used, if desired, for the lighting of outside yards and open spaces. The candle-power is given as 500, and the consumption of oil as one English gallon for thirty hours' burning.

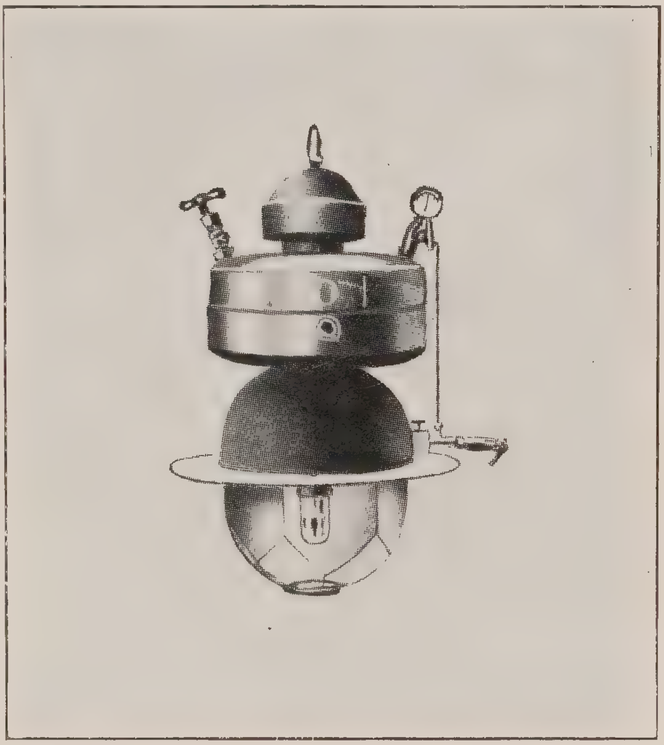

FIG. 1.—Kitson incandescent oil lamp for factory lighting.

The reservoir is first filled one-third full of a good quality petroleum, since inferior varieties lead to carbonisation and a deposit of soot, and air is then forced in by means of a small hand pump until the gauge registers a pressure of 55-75 lb. per square inch. A valve below the pressure gauge is then opened, and the oil is allowed to flow along the tubing to the vaporising tube in the lamp. This vaporising chamber is maintained at a high temperature in a manner shortly to be described, and the vapour is then ejected into the mixing cup and thence into the mixing tube. During its progress the vapour carries with it a sufficient quantity of air to support combustion, the vapour and air becoming thoroughly mixed to form a highly combustible gas, which is led into the burners and brings them to incandescence.

SPECIAL FEATURES OF INCANDESCENT OIL LIGHTING.

The light produced by the burning of a mixture of vaporised petroleum and air in an incandescent mantle is claimed to be softer and more diffusive in its properties than any other form of artificial light, and the nearest approach to sunlight yet devised.

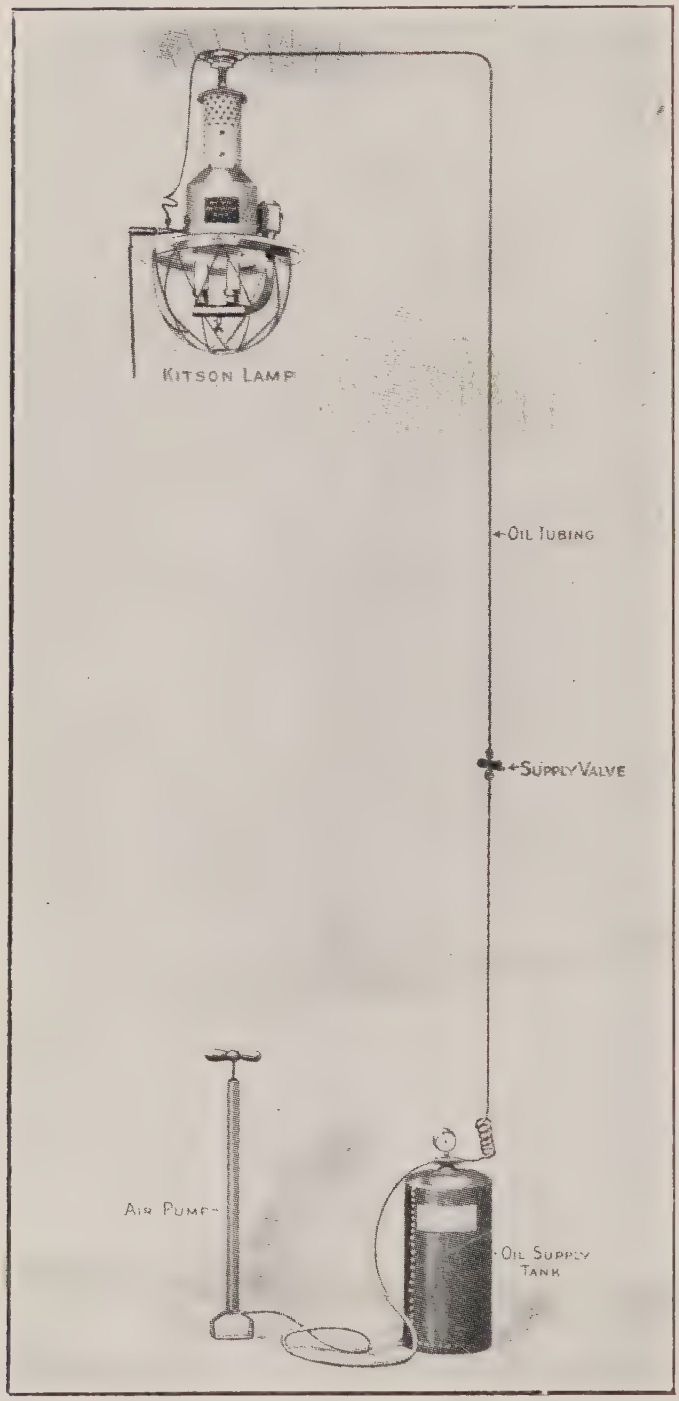

Fig. 2.—Incandescent oil lighting system.

Certainly oil lighting is exceedingly agreeable from the work-people's point of view, and lends an air of cheerfulness to the surroundings.

The adjective cold does not apply to the light produced from incandescent oil lamps, and the harsh glare experienced with high candle-power arcs and some other forms of electric light is entirely eliminated.

Incandescent oil lamps are applicable for nearly all inside and outside lighting purposes, and, since no expensive machinery is involved, the lamps can be immediately erected by any person provided with the necessary instructions and without the necessity for laying cables or mains of any description. For example, a small oil tank, a hand air pump, and the lamp comprise a complete Kitson plant (fig. 2). For emergency factory lighting and for rapid extension work, when the labour involved in mains extensions is an impossibility, the system is without a rival.

The upkeep is exceedingly small, one gallon of petroleum burning for fifteen hours in a 1,000 candle-power, and for twenty-seven to thirty hours in a 500 candle-power lamp. From experience the life of a mantle is 150 hours, and at pre-war rates the total cost per 1,000 candle-power hours for oil and mantles is considerably below one penny.

Occasionally works managers question the system from the point of view of safety. It is felt that a working pressure of 55 to 75 lb. per square inch in the reservoir may introduce a factor of danger into the equipment. The system, however, is perfectly safe, for the whole of the tubing and tanks are subjected to a pressure of five times the working pressure before installing, while in case of accident to the tubing the automatic check valve immediately cuts off the supply of oil. The oil, further, is not vaporised until it reaches the lamp, and then only in minute quantities, while the new Kitson thermostatic valve admits the oil to the vapour tube only when the latter is sufficiently heated. Should the vapour tube, for any reason, cool below the temperature of vaporisation, the valve closes automatically, shuts off the oil supply, and entirely obviates the danger of flooding or smoking.

METHOD OF LIGHTING INCANDESCENT OIL LAMPS.

Once an incandescent oil lamp has been started, the vaporisation of the oil continues automatically, the heat from the lamp being sufficient to maintain the parts into which the oil is injected at the necessary temperature. From the foregoing description it will be understood, however, that before the oil can be turned on the vapour tube must be heated by some extraneous means, and four chief methods have been adopted for this purpose.

1. *The Torch System.*—A hand torch filled with asbestos fibre is supplied. This is dipped into spirit, petrol, or petroleum, lit and passed through funnels which are fixed to the lamps. The torch is pushed in as far as it will go, and then rests underneath the vapour tube. After burning for about one minute the vapour tube will be sufficiently hot, and the oil may be turned on. If, however, the oil is turned on before the vapour tube is properly heated the result will be a blackening of the mantles and smoke. Should this occur the oil valve must

be closed and the tube heated as before. It is better to afford ample time for heating the vapour tube, and for a person unfamiliar with the lamp it is perhaps better to allow two minutes for this heating until familiarity with the lighting has been attained. A little practice will soon enable one to discover when the vapour tube is sufficiently hot, but to avoid the possibility of smoke when starting the lamp it is better to fit the thermostatic valve, which is described later, and not to leave the heating to the discretion of the person lighting the lamp.

2. *Gas Ignition System.*—In cases where gas is already in use and pipes are laid in the buildings, the simplest method of starting oil lamps is by means of a small attachment to the gas pipe. A Bunsen burner and pilot jet are provided underneath the vapour tube, and the oil lamp is lighted in the same way as an ordinary gas lamp. By pulling a chain the gas is turned on and ignited from the pilot jet, and in about one minute the oil lamp is ready for lighting. After the mantles are at full incandescence the Bunsen must be turned off. The gas consumed is a trifling quantity.

3. *Electric Ignition System.*—In cases where lamps are at a great height and ordinary gas is not available a carburetter is provided (which is saturated with petrol), and electric battery and a sparking coil, so that a Bunsen flame may be obtained by forcing air through the carburetter which is connected with the pressure tank. The ignition of the Bunsen is effected by an electric spark. This system is recommended only where the lamps are difficult of access, and where ordinary gas is not available, as it is much more expensive than the other systems.

4. *Spirit Ignition System.*—In this case a metal cup containing asbestos is partially filled with methylated spirit and ignited, and the heat ascending to the vapour tube produces the necessary vaporisation. This method is only used for lamps of the fount type, and for the vertical vapour tube lamps.

The Kitson Thermostatic Valve.

The chief objection raised by incandescent oil lamp users in the past has been the difficulty with regard to the lighting, or starting, of the lamps from the cold state. In the hands of persons unfamiliar with such lamps a danger has undoubtedly existed of the oil being turned on before the vapour tube was sufficiently heated to vaporise the oil, in which case the lamp was frequently flooded with oil, the mantle blackened with smoke, and a considerable amount of time expended before the lamp could again be put in working order.

The thermostatic valve has been designed to overcome this trouble and to render the lamp automatic in its action, the operator having nothing to do but pour in a little spirit and light it, or, in the case of gas ignition, to turn the gas cock, the valve performing the rest of the operations automatically.

The principle of the valve is the differential expansion of two metals controlling the valve and valve seat respectively. The outer tube A (fig. 3) when sufficiently hot expands and lengthens, and the spindle B is drawn away from the steel plate, thus allowing oil to pass through the passage D into C, and so into the vapour tube. When the lamp is extinguished the outer tube A cools, and the plate is forced by the spindle on to its seat, thus shutting off the supply of oil to the vapour tube. Care must be taken not to adjust the valve spindle while the tube is hot.

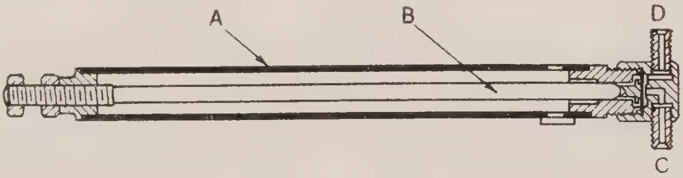

FIG. 3.—Thermostatic valve.

The thermostatic valve can be applied to any of the Kitson lamps, and not only renders the system of lighting as simple as possible, but makes it so that it may be placed in the hands of any unskilled labourer.

In fig. 4 a section of one of the latest patterns of lamps embodying electric ignition and the thermostatic valve is shown.

The oil passes through the supply tube to the thermostatic valve and thence to the vapour tube, where it is vaporised. The oil vapour then flows through the venturi tube, where it draws in air, the gas then descending through the mixing tube to the mantles.

It is necessary, in case the mantles do not at once become brilliant, to raise and lower the needling rod sharply. This operation causes the needle to clear the small outlet hole in the vapour tube plug and allow the vapour to pass freely, and should be repeated whenever the light becomes dim.

The vapour tube should be cleared occasionally, depending upon the hours of burning, while it is also necessary that the venturi tube should be taken out and cleaned about once every three months.

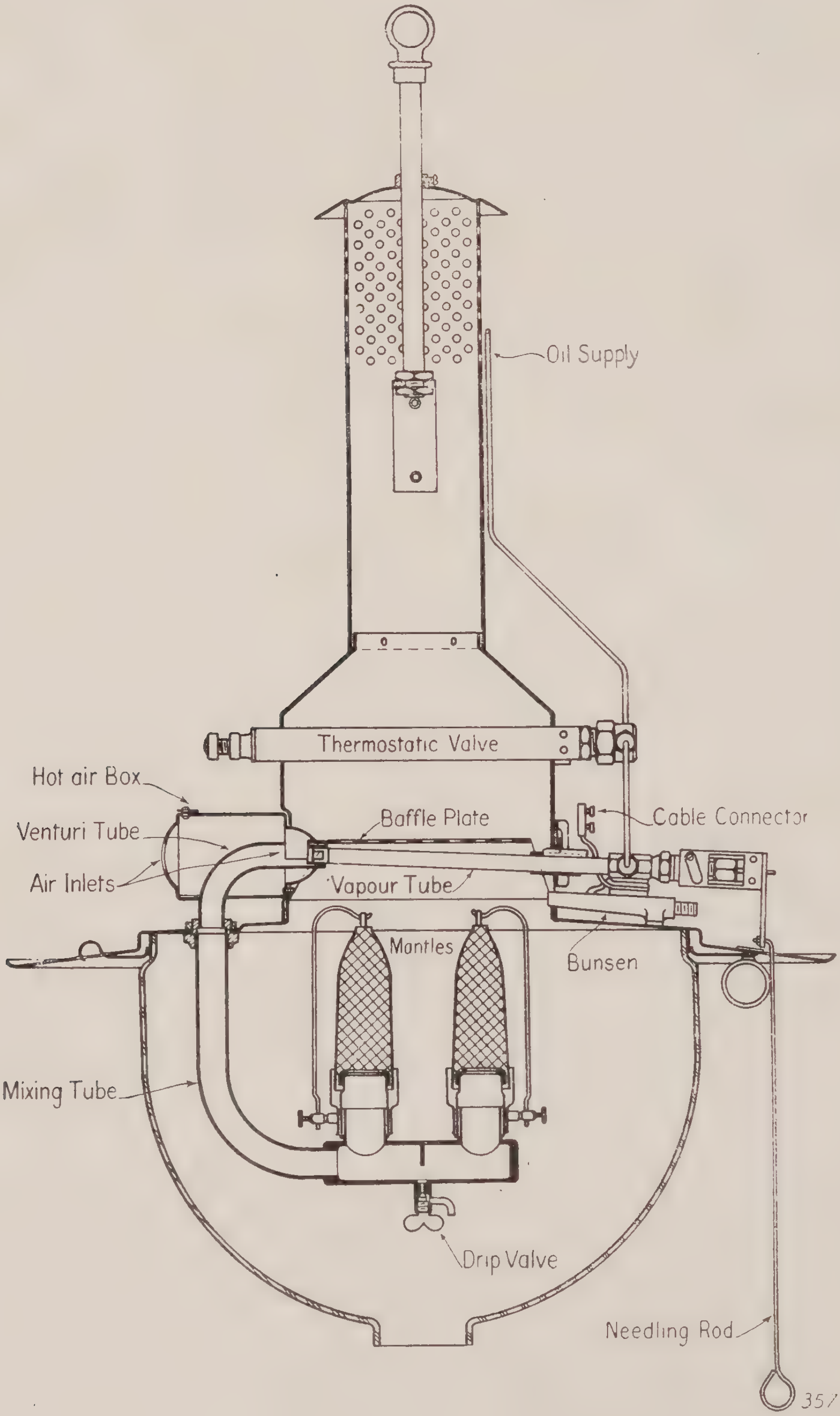

FIG. 4.—Latest type Kitson lamp, embodying electric ignition and thermostatic valve.

INSTALLATION OF AN INCANDESCENT OIL LAMP.

Mention has already been made of the J 12, a 500 candle-power oil lamp suitable for factory lighting. The instructions to be followed when installing are simple, and as the lamp is typical of factory lamps it is thought advisable to give the instructions in full, as well as a working diagram of the lamp itself (fig. 5). It will be observed that the lamp is self-contained, being fitted with a collar tank T and the necessary gauges. The lamp being assembled, connect one end of the oil line (J 105) to the nipple of the supply valve (J 102) on the tank T, and then carefully bend the oil line and connect the other end to the nipple N on the vapour tube (J 1).

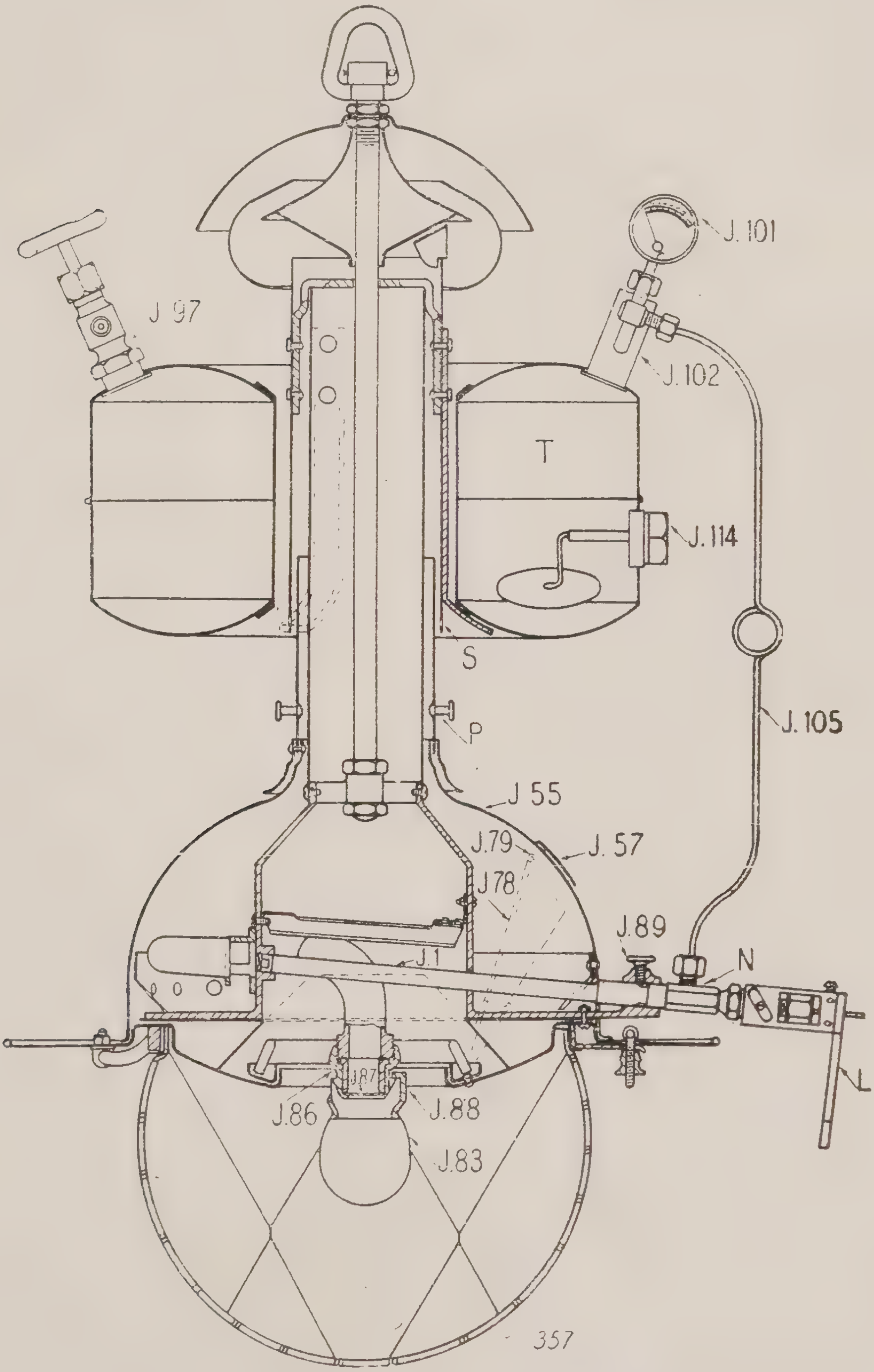

FIG. 5.—Diagram of the Kitson lamp.

It is very necessary that tight joints should be made, and, if the lamp is to be suspended within eighteen inches of a wooden ceiling or roof, an asbestos ceiling plate should be fixed over the lamp.

To Fill the Tank T.—When filling the oil tank first open the air valve (J 97) by turning the wheel, and then unscrew and take out the air valve and pour in petroleum until the dial (J 114) indicates full. Then replace the air valve and screw down tightly, afterwards connecting up the air pump and raising the pressure to not less than 30 lb. Close the air valve and uncouple the pump.

Burning off the Mantle.—The mantle (J 83) is tied to the mantle holder (J 88), which is slipped over the Bunsen tip (J 86), and whenever a new mantle is used it is necessary to burn it off before proceeding to light the lamp. To do this it is only necessary to place a lighted match to the bottom of the mantle after having first fixed the latter to the burner of the lamp.

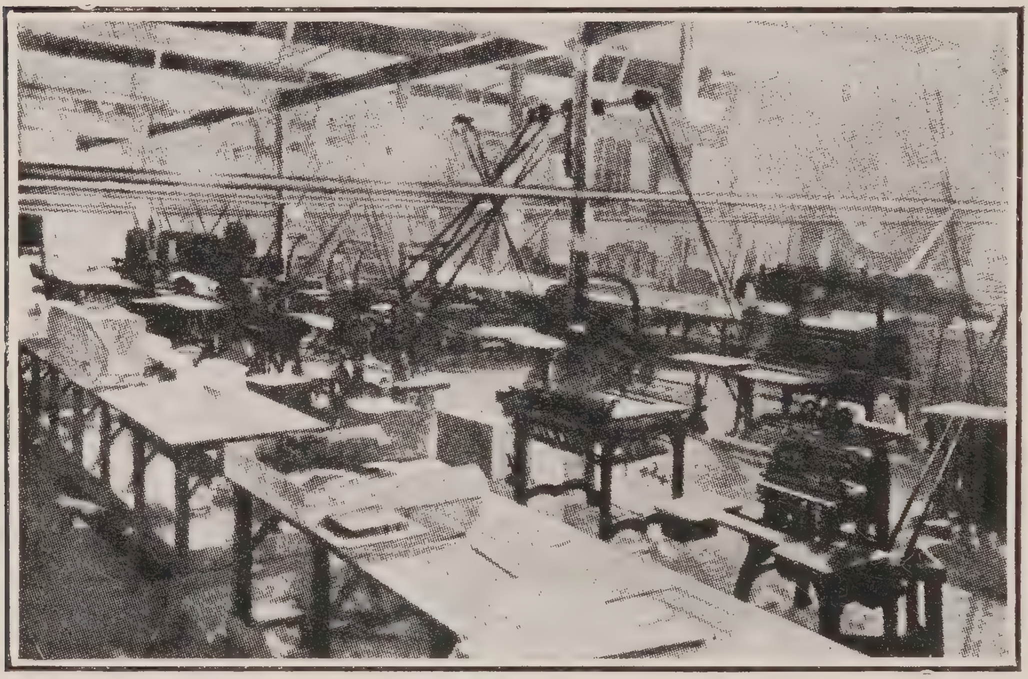

Fig. 6.—Kitson lamps installed in a printing works.

Lighting the Lamp.—By means of the spirit can provided with the lamp one dose of methylated spirit is poured into the torch funnel (J 78) through the small shuttered side (J 57) in the hood, and a lighted match then applied to the asbestos cord (J 79) in the torch funnel, the vapour tube (J 1) being thereby heated. After two minutes the oil may be turned on gradually at the supply valve (J 102).

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PRECAUTIONS.—Occasionally it may happen that the lamp flares after the oil has been turned on, in which case shut off the oil supply and wait until the flaring ceases, turning on the oil again slowly. If the flaring continues the oil should be again turned off and the operation repeated till it is seen that the mantle is fully incandescent.

The vapour tube (J 1) should be cleaned every week if the lamp is in daily use. To remove it, uncouple the oil line at N and release the set screws (J 89), when the vapour tube may be withdrawn. On replacing the vapour tube, see that it is pushed right home on its seat.

Water in the paraffin is indicated by the light going dim and flaring after the lamp has been burning for some time. The air should be released from the tank and the paraffin emptied out, a new supply being used after the tank has been carefully drained.

ADVANTAGES OF INCANDESCENT OIL LIGHTING.

The advantages of oil lighting may be briefly summarised as follow :

(1.) Economy of installation, requiring :
  (*a*) No expensive generating plant.
  (*b*) No mains or cables.
  (*c*) No skilled labour.
  (*d*) No interference with thoroughfares.
  (*e*) Very little floor space.

For example, at the National Export Exhibition, Philadelphia, one of the largest sections was lighted by Kitson lamps, there being 100 lights, each of 1,000 candle-power, on a single circuit.

The floor space required for the plant, oil tank, etc., was only 8ft. × 10ft., and necessitated but the occasional supervision of one attendant.

The joint report of Sir Boverton Redwood and Professor Lewes furnishes interesting reading in this connection. They state :

"It has long been recognised that in the combustion of petroleum for illuminating purposes advantages similar to those obtained in the use of gas would result from the employment of an incandescent mantle, and many attempts have been made to construct a suitable lamp for the purpose. In the Kitson light the difficulties which have stood in the way of the use of mineral oil in a mantle lamp have been successfully overcome by the simple device of obtaining oil vapour under sufficient pressure to ensure its drawing up an ample supply of air for its complete combustion in a burner of the Bunsen type, and so enabling the high calorific value of the oil to be fully utilised in the most efficient way, a system of illuminating large spaces being thus provided which in respect of efficiency and economy surpasses every other means of lighting.

"In a long series of experiments made with various types of the Kitson lamp it was found that the average illuminating power was slightly over 1,000 candles, and although with a new mantle of perfect fit and with full pressure in the reservoir it was possible to obtain values as high as 1,250 and even 1,300 candles, yet in ordinary work 1,000 was the fair mean result over extended periods of time. The colour of the light more nearly approximates to that of daylight than is the case either with the mantle as ordinarily used or the electric arc.

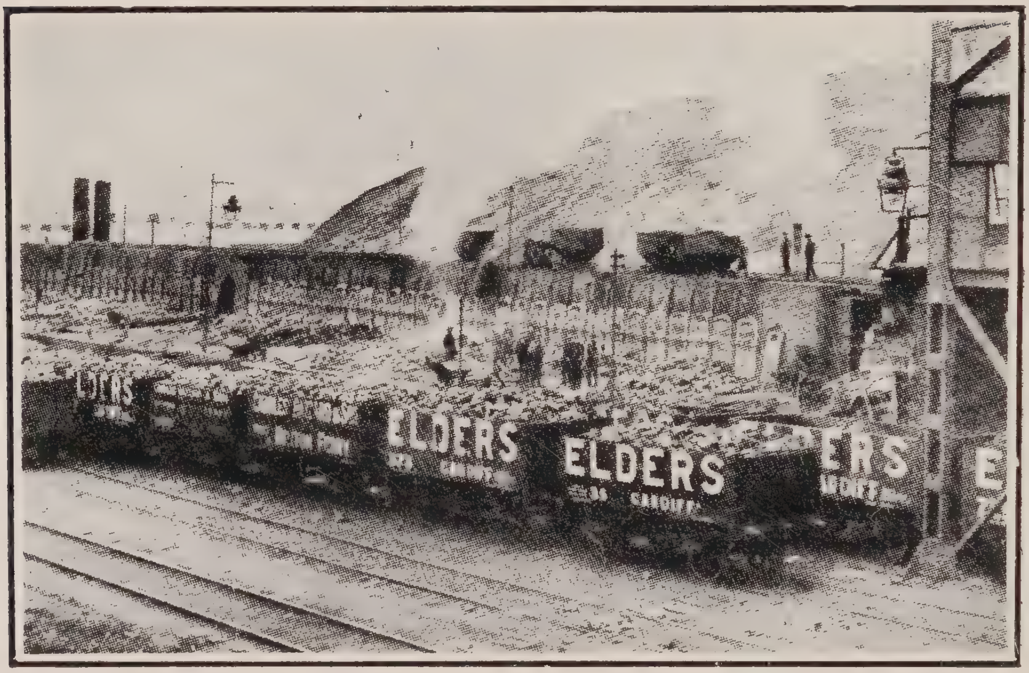

Fig. 7.—Kitson lamps at a colliery siding.

"In these experiments the consumption of oil averaged 0.1 gallon of oil per 1,000 candles per hour. (This consumption has since been reduced to one gallon per 1,000 candle-power for twelve hours' burning.)

"The light-emitting power of the mantles used was not affected to a greater extent than with any pressure system of gas incandescent lighting, a mantle which at the start was giving a light of 1,000 candle-power still yielding 1,000 candles after thirty hours' burning.

"The candle-power of the light emitted by the mantle varies directly as the pressure of the oil reservoir, and although this makes a considerable difference with a small reservoir, with the size used for street lighting it only means a fall of from 1,200 to 1,000 candles in twenty-four hours, a difference not distinguishable to the eye in ordinary practice.

"The pressure in the apparatus up to the point of emission of the oil vapour is practically the same as in the reservoir, but at the burner head this is reduced to atmospheric pressure.

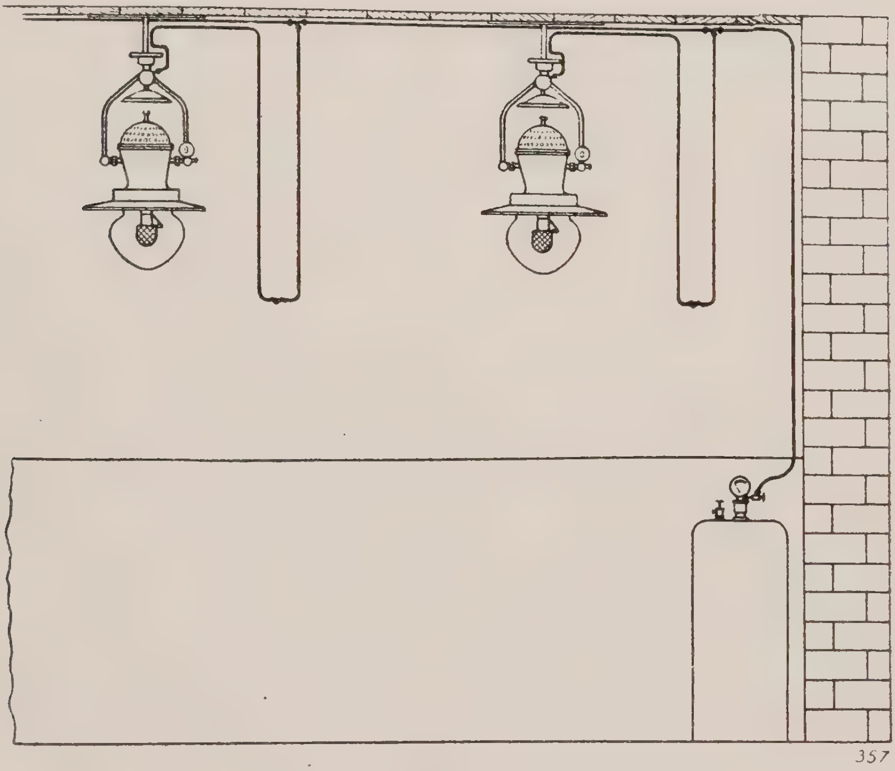

FIG. 8.—Oil lighting system.

"In the gasifying, or more properly vaporising, tube which receives the heat escaping above the mantle and utilises it in converting the oil into vapour, the temperature just falls short of that necessary to decompose the oil, with the result that the amount of carbonaceous matter deposited in the tube is extremely small, being only 0.226 gramme in eighteen hours.

"The working parts of the lamp are so arranged as to admit of the use of a downward reflector, which does away with the trouble so common in incandescent lighting of the largest amount of light being emitted upwards at angles above the horizontal, with the result that the Kitson lamp gives its maximum between angles of 10° and 30° below horizontal, and is still giving very nearly its horizontal efficiency at 40-45° below, which may be taken as the important working angles.

" Except at the moment when vaporisation of the oil commences on the lamp being lighted, we find that the combustion is so perfect that the products of combustion are odourless.

" We have given special attention to the question of the safety of the system in view of the circumstance that the oil is supplied to the lamp under pressure, and we have arrived at the conclusion that the system is not only adapted for use in the lighting of large areas in the open air, but can also be safely employed as a source of light in railway stations, factories, and other buildings. It is, of course, obvious that safety is a relative term, and that no system of artificial lighting can be entirely free from risk of fire ; but we are of opinion not only that the Kitson system may be regarded as the safest means of obtaining a given amount of light from mineral oil, but also that it is not less safe than the electric light or gas."

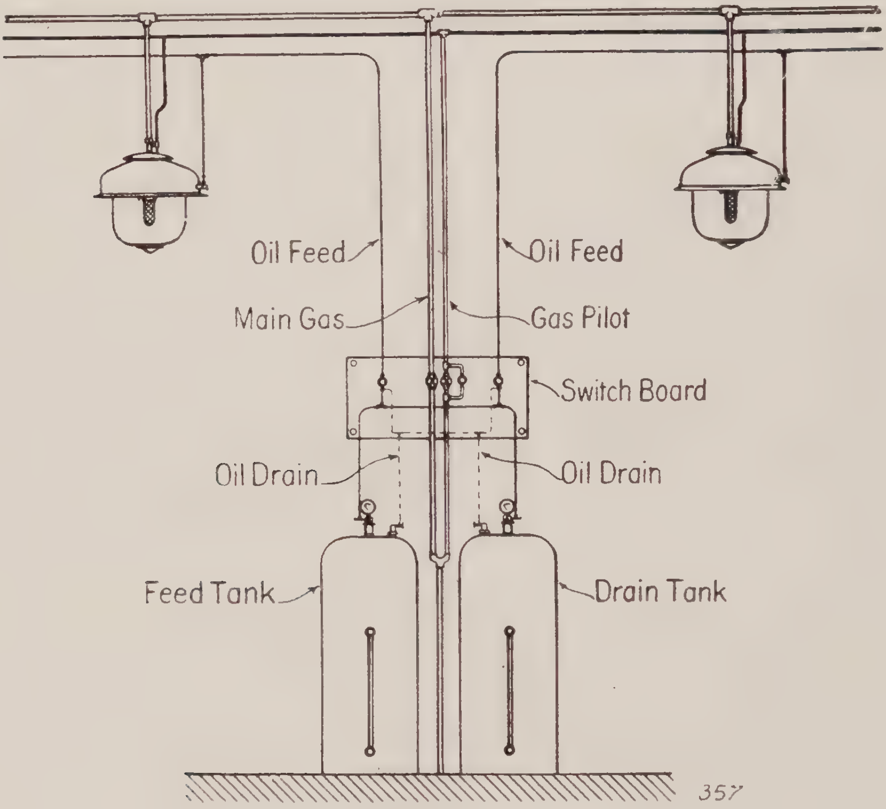

FIG. 9.—Central oil lighting system with gas ignition.

FACTORY LIGHTING ON THE CENTRAL SYSTEM.

In cases where electric or gas lighting is inadvisable, incandescent oil lighting has been recognised as the ideal factory light. A great disadvantage hitherto has been the time and trouble occasioned in lighting and extinguishing the individual lamps, but the difficulty has now been overcome by the Kelite central lighting system.

When a number of lamps are required in one room, as in factory lighting, the lamps may be so controlled that instantaneous lighting or extinguishing of the whole number is possible.

The oil supply is contained in a steel reservoir, which may be placed in any convenient position, either inside or outside the building, and the oil is conveyed through fine copper tubes (about $\frac{1}{8}$in. to $\frac{3}{16}$in. diameter) to the various lamps by means of air pressure supplied by a hand pump or compressor (fig. 8).

FIG. 10.—Iron foundry illuminated by incandescent oil lamps.

The lamps may be placed at any reasonable distance from the reservoir, from which it will be seen that a factory equipment may very readily be erected, and that the space required for the tanks, etc., is a negligible quantity.

The small oil tubes are run along the wall or ceiling in just the same manner that electric wires are, and occupy about the same amount of room and time in fitting.

The system is a highly convenient one from the works lighting point of view, since the oil is confined to one place, and it is unnecessary to keep oil at any other part of the building, except at the central supply. If gas is already installed in the works, the oil lamps may be attached to the gas pipes, and started by using a pilot gas jet and Bunsen to heat the vapour tube. In this case the use of spirit for heating is unnecessary, and the lamps may be lighted by merely pulling the gas chain (fig. 9).

Spacing Rules, etc.

Incandescent oil lamps have the working parts so arranged as to permit of the use of a downward reflector, and in the Kitson lamps the maximum candle-power is afforded between the angles 10° to 30° below the horizontal, while the horizontal efficiency is practically maintained at 40° to 45° below the horizontal. An extensive distribution is thus afforded, and the distance apart of the units should equal twice their height above the working plane. In case of doubt the bench tops should be taken as the working plane, except in particular cases, foundries for example, when the chief work is carried out on the floor itself.

CHAPTER IX.

NATURAL LIGHTING.

IN previous chapters it has been repeatedly emphasised that light is a tool, the most important tool placed at the disposal of the workman.

The truth of this statement will be immediately evident if we remember that without light all other tools are useless, and that the utility and value of all works, factories, and offices are determined by their lighting arrangements.

It is therefore surprising to find that in the United Kingdom no general provisions in respect of lighting occur in the Factory Acts, the only reference to the subject, to quote from the report of the Lighting Committee, being found in the Factory Act of 1901, which specifies "adequate lighting" amongst the conditions as to which a local authority must be satisfied before an underground bakehouse is certified as suitable for use.

The regulations issued by the Board of Education relating to the construction of schools prescribe, amongst other things, adequate window space (one-fifth of the floor area for class rooms), suitably placed windows, and light-coloured walls. Buildings under the control of the Local Government Board are also subject to special instructions issued by the Board, in which adequate window space is one of the points to which attention is drawn, while, further, the building byelaws adopted by many local authorities often require that in new buildings every habitable room shall have at least one window, and that the total window area shall amount to at least one-tenth of the floor area.

Otherwise the natural lighting of buildings by means of windows in the walls and ceilings of the various rooms appears to have entirely escaped the notice of responsible authorities, and practically no definite rules exist which will enable the area and arrangement of the windows necessary to provide a correct illumination to be determined.

Further, as pointed out by Mr. Waldram, it is still more strange to find no recognised criterion in existence as to what is adequate natural illumination for any given purpose, such as an office or a workshop. For it must be remembered that the correct solution of the lighting problem, whether daylight or artificial, involves enormous sums, both of initial building expenditure and annual expenditure such as rent and upkeep, and the ultimate profit or otherwise of the whole concern.

CONSIDERATIONS OF GOOD NATURAL LIGHTING.

To the lay mind natural lighting invariably suggests the provision of a sufficiency of windows, in much the same way that a number of lamps in the field of view satisfies all the artificial lighting requirements of the average user. Now we have endeavoured to show that artificial lighting presents a complex problem for solution, and natural lighting involves the same considerations. It is to be regretted, therefore, that, while the researches of engineers and others have given illuminating engineering a definite status with reference to the use of artificial light, yet the vital problem of natural lighting has so far, comparatively speaking, been left almost untouched.

Good natural lighting permits of clear and easy vision under all conditions. A complete absence of eye-strain is essential in the best interests of the workman and his work, while freedom from glare, due to the incorrect use of prismatic glass or exposure to direct sunlight and reflections from polished metals, should also be insisted upon.

In addition to the lighting considerations, there are, however, many other factors of vital importance that must on no account be overlooked.

Dr. Knopf, Professor at the New York Medical School, in a recent statement submitted to the Heights of Buildings Commission, laid great stress on the importance of securing adequate lighting and sunlight in buildings to prevent the spread of tuberculosis. He stated that "Tuberculosis, which is propagated by bad air, foul air, and lack of sunlight, causes annually a loss of 200,000 citizens to the United States. This disease could be largely prevented if we would live and work in pure air, in air relatively free from mineral and vegetable dust, and last, but not least, if we would construct buildings in which we live and labour so as to allow sunlight to enter more freely."

Works in crowded areas are for this reason to be condemned. Rent considerations and lack of space necessitate buildings of many storeys, and it is no uncommon thing to find works in crowded manufacturing districts with three, four, or even more storeys, all occupied with some form of manufacturing process.

In such areas most of the rooms, even at the front, are inadequately lighted, and in the parts of the rooms remote from the windows artificial lighting has nearly always to be relied upon.

We are ourselves familiar with several engineering works in the Lancashire area where such conditions hold, and where artificial lighting has to be relied upon almost entirely throughout the year.

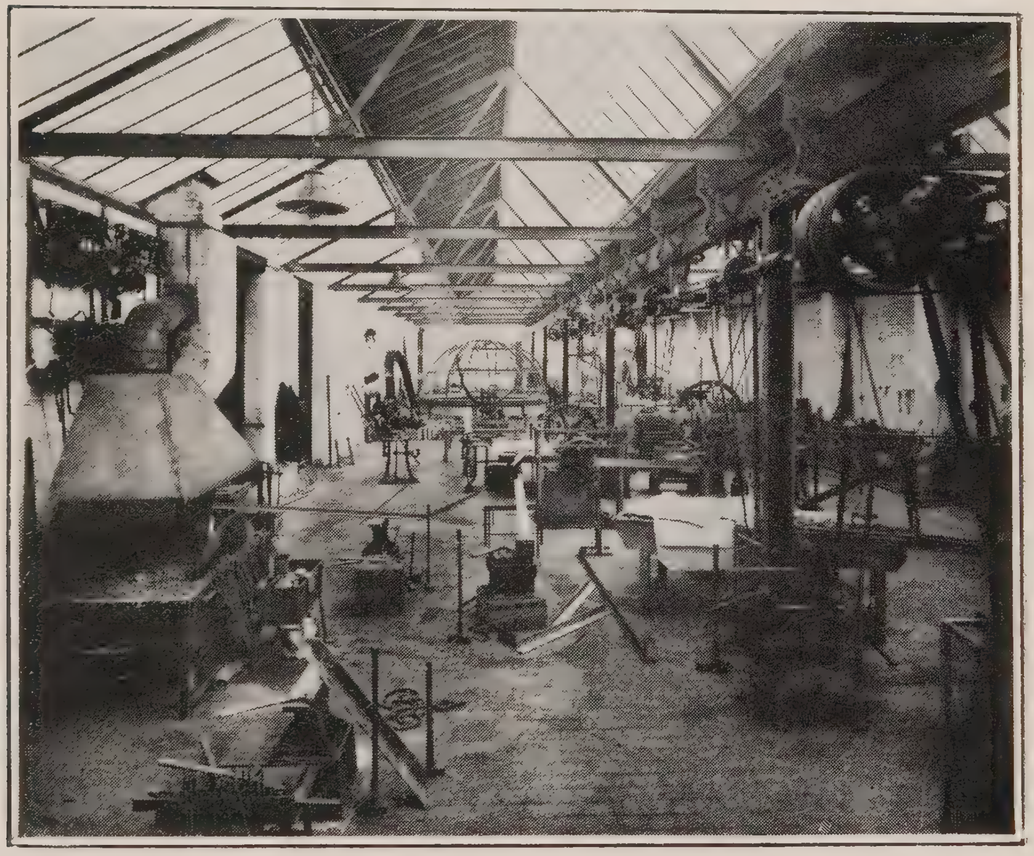

FIG. 1—" Saw-tooth " roof lighting by the Luxfer Prism Syndicate, Ltd.

In this connection, the words of a prominent speaker at the New York Municipal Art Society are of interest. " We build hospitals," he remarked, " for the poor consumptive, and then we turn round and erect structures where consumption may breed, so that we shall not lack for patients."

On the other hand, good natural lighting is capable of conferring inestimable benefits upon the community at large, and since the advance of civilisation makes us more and more dependent upon artificial lighting, we should endeavour to take the fullest advantage of the benefits to be secured by the correct use of daylight and sunlight in all our works.

PRESENT NATURAL LIGHTING OF FACTORIES.

Three systems of natural lighting present themselves, according to the construction and situation of the building.

In single-storied and on the top floor of multi-storied buildings, roof lighting, or a combination of roof and side lighting, is possible. Side, or lateral, lighting only is possible in buildings of two or more storeys.

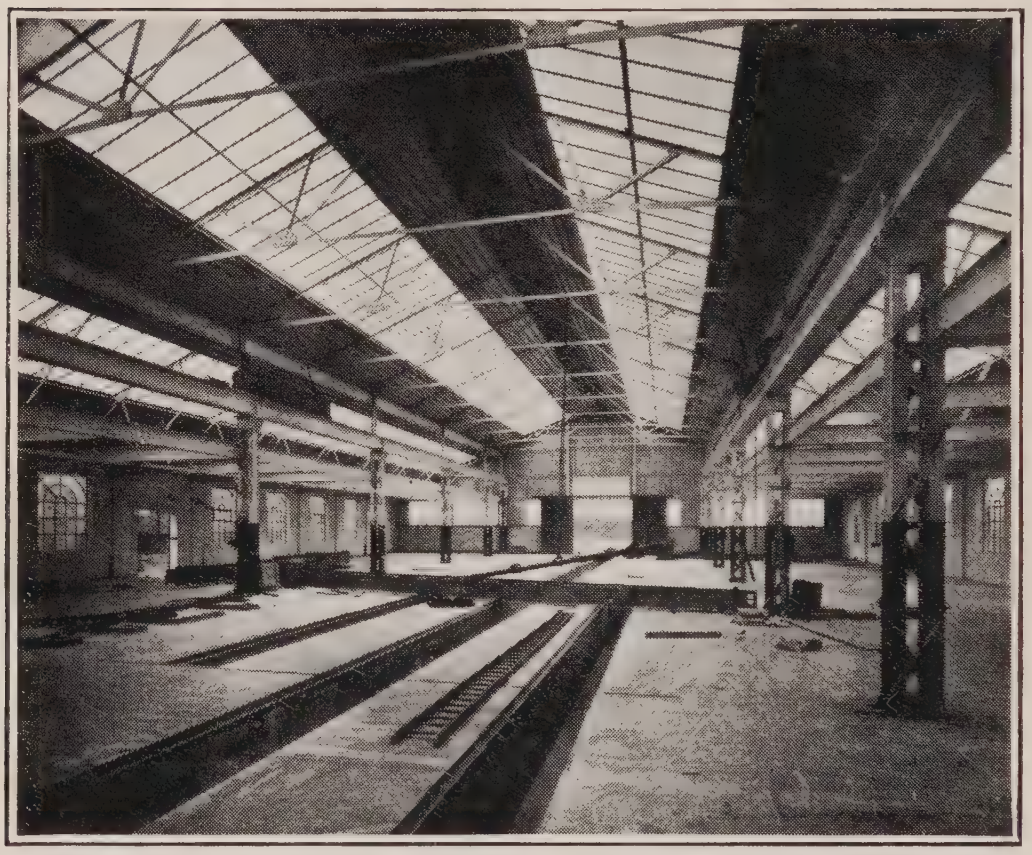

FIG. 2.—Span roof for large engineering works by the British Luxfer Co.

ROOF LIGHTING.

Roof, or top, lighting is the method usually adopted where rents are low and single-storied extensions are possible, or where a uniform and strong illumination is essential.

Large engineering works, in which the heavy nature of the work precludes the erection of a second storey, are also admirably adapted for roof lighting, and in the majority of the factories springing up so rapidly at the present time the advantages of top lighting have been fully recognised.

The varieties of skylights available are numerous, and the natural lighting of a factory mav be derived from an ordinary skylight, a roof lantern, a span roof, a "saw-tooth" roof; also combinations of the above, with the addition of lateral, or side, lighting.

The saw-tooth type of roof is desirable where a uniform and strong illumination is required, and, while the use of such a roof is almost essential in weaving sheds, many engineering firms have also recognised the advantages of this form of lighting.

Thus in fig. 1 a saw-tooth roof is shown with additional windows in the long side. The short side of the roof in itself is sufficient to ensure a uniform and strong illumination. The additional glass is a refinement, but its use in the present case is warranted by the fine and intricate nature of the work carried out.

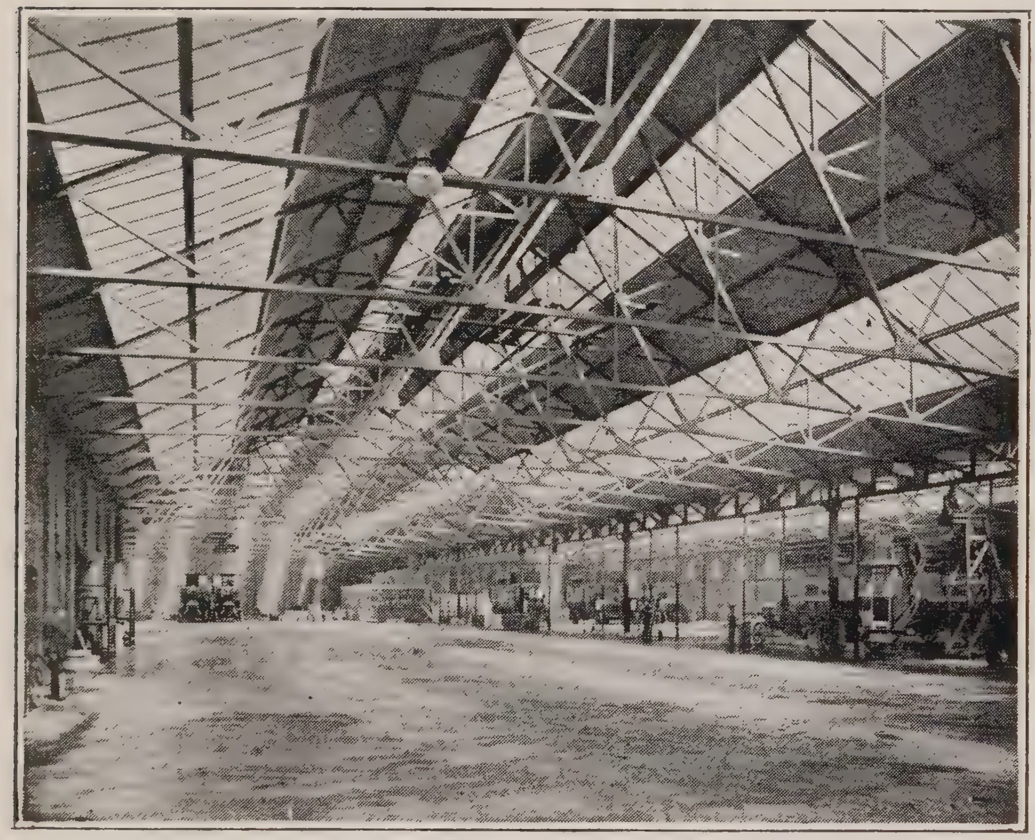

FIG. 3.—Large span roof in a garage.

In all cases the long slope should be kept clean and whitewashed, and the provision of white walls also adds much to the effectiveness of the installation.

For toolrooms, ball bearing works, engine machining and assembly, and other places where a high intensity of well-diffused light free from shadow and glare is desirable, roof lighting of this nature leaves nothing to be desired.

Span Roof Lighting is essential in large structures, and where heavy cranes are in use, while in many cases large engineering works have the major portion of the roof and walls constructed of glass in special steel frames. The illumination with well-designed span roofs is very even, and may vary from 2% to 10% of the outside unobstructed illumination.

In fig. 2 a large span roof for a heavy engineering works is shown. The evenness of the illumination may be judged from the appearance of the ground. No dark corners exist, and in such a factory the possibilities of inferior work are greatly reduced. Bench work near the walls is facilitated by the addition of side windows, while the white paint on the walls and girders ensures the minimum of light absorption.

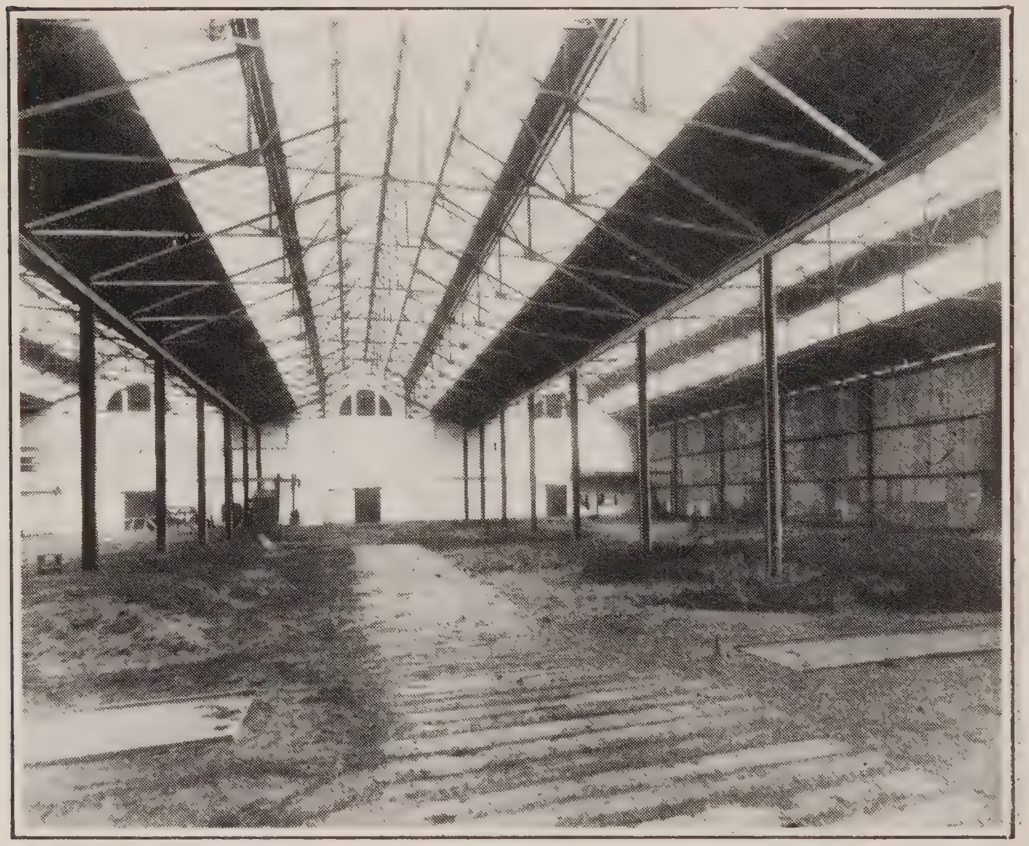

Fig. 4.—Foundry roof lighting.

A very fine example of a span roof is shown in fig. 3, the premises being the garage of a large motor 'bus company ; the floor area exceeding 35,000 square feet.

That it is possible adequately to illuminate any area, however large, by roof lighting will be at once apparent, while the ease with which detail may be studied bears evidence to the intensity and evenness of the resulting illumination.

A solution of the very complex problem of foundry lighting is afforded in fig. 4, which shows a span roof providing an adequate illumination over the whole of a foundry floor.

When the nature of this or any other foundry floor is considered, it will be evident that roof lighting of a liberal nature is a necessity, while it is also of the utmost importance that all walls, girders, etc., should be kept clean and white. The Departmental Committee found that the effect of dirty glass was very noticeable in all cases of foundry lighting, and that in one particular instance the mean daylight factor of a foundry with dirty glass was only .38% compared with 5.8% in the case of an inferior installation with clean glass.

LATERAL LIGHTING.

Lateral lighting is derived from windows let into the side walls, and for all ordinary purposes is inferior to top lighting. A workman engaged on bench or other horizontal work requires light from above. Side lighting is, therefore, inferior to top lighting. For some purposes, however, such as painting and erecting, light is required from a horizontal direction, and lateral lighting is equal to top or roof lighting in this respect.

In modern factories a very large proportion of the wall space is occupied by windows, the expression "walls of daylight" being used by one firm with reference to their constructions.

It will be evident, however, from fig. 5 that there is a limit in the width of room (for a given height) beyond which the illumination falls below what can be considered adequate.

Unevenness is a further drawback to lateral lighting, for fig. 5 will again make it clear that, although part of the floor near the window may be well lighted (A), the further positions of the room may be in need of permanent artificial illumination (B). Comparison with fig. 6 is all in favour of roof lighting, a strong uniform illumination being secured over the whole of the floor area.

Far too many people take the natural lighting of a works or office for granted, and insufficient attention is paid to this vital factor in our daily lives when a new building is being planned or improvements in an old one meditated. The impression is abroad that if the windows are large enough daylight is bound to enter. Yet the direct source of daylight—the sun—cannot be depended upon, and shines only about one-third of the time it is above the horizon, constantly changing its position from hour to hour and from one season to another. The sky is the one source of daylight that may reasonably be depended upon, and yet sky brightness has received very little attention from meteorological investigators. Wind direction, temperature, and many other such things are daily recorded, but the most important factor in daylight lighting has been almost entirely neglected.

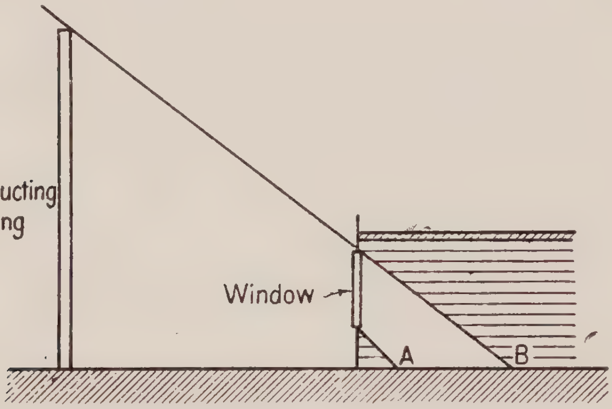

FIG. 5.—Obstruction of light.

It has been estimated that during an ordinary cloudy day an opening one foot square in the ceiling of a small room is equivalent to a twenty-five candle-power lamp, supposing the ceiling to be very thin and the opening to be uncovered.

In the case of an ordinary lantern light or skylight, this value is much too high, from five to ten candle-power being nearer the figure. The loss is occasioned by glass obstruction, dirt absorption, the framework and opaque sides of the lantern, and the thickness of the ceiling.

Beyond this value it would appear that no other direct candle-power observations have been made.

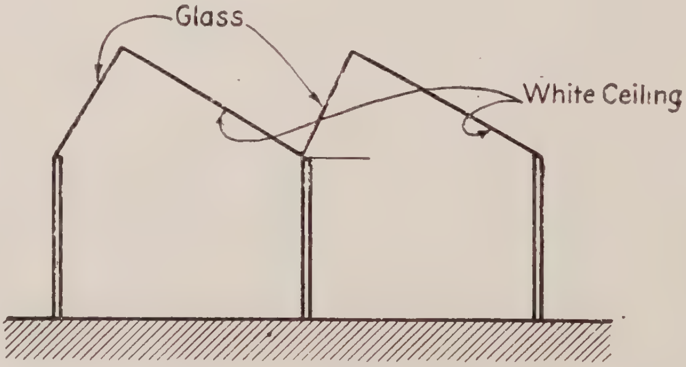

FIG. 6.—Roof lighting.

FACTORS GOVERNING DAYLIGHT ADMISSION.

The natural illumination at a point on a horizontal plane in a room depends on (1) the amount of sky visible from that point, (2) the brightness of this area of sky, and (3) the angular elevation of the sky.

Sky brightness varies within very wide limits according to the time of the year and day, and may even vary enormously from the average value in the course of a few minutes. As a physical magnitude it is, however, capable of accurate definition and measurement.

If B is the brightness of the visible sky in candles per square foot, then the illumination at any point in a room lighted by vertical windows may be determined by the formula:

$$I = B\,\omega \sin \theta,$$

where ω is the solid angle subtended by the visible sky at the point in the plane of reference, and θ its average angle of elevation.

As $\sin \theta$ is a quantity increasing with θ, the value of high angle light is demonstrated.

Only a comparatively small percentage of the flux of light reaching the windows of a factory is effective in the illumination of the interior. Much of the light is needlessly absorbed by the walls, floor, and ceiling of the room. A further portion is obstructed owing to the shape of the windows, while objects placed in line with the windows and the dirt on the latter all contribute to a greatly reduced inside illumination. In fig. 7 two windows of equal area are shown, but, although equal in area, the lighting results will be widely different. Daylight will be received through the vertical window at a much more favourable angle for interior illumination, while if the sky is obstructed by neighbouring buildings the advantages of the vertical window will be greater still. Reference to the formula will make it clear that with the vertical window an enhanced illumination is received at any point within the room from which the sky is visible.

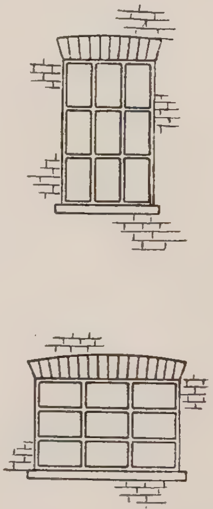

FIG. 7.—Two windows with same area, but different lighting qualities.

OBSTRUCTION TO LIGHT.

It is the usual practice to determine limiting angles at which the light is completely intercepted by the window sills, columns, or other obstructions, and rules are laid down with the object of maintaining a minimum angle of light. Thus in London (U.S.A.) a building may not be put up to obstruct the light of an adjoining lot by more than $63\frac{1}{2}^\circ$.

Now, the entrance of daylight is concerned with sky obstructions, and in planning a new building all such obstructions must be taken into account.

For example, a tall building situated directly opposite the windows of a works or office would result in the blocking out of a large proportion of the light that would otherwise enter the rooms. Sky obstructions situated so as to intercept high lights are also much more effective in causing a decrease in the light entering a room than a corresponding area of obstruction situated low down or at a distance.

METHOD OF DETERMINING SKY OBSTRUCTION.

In daylight calculations the actual skyline as formed by the obstructing buildings must first be determined. It is of no use to install large vertical windows in walls directly faced by buildings which cut off the light to a marked degree. Many of the new works extensions hastily erected as a direct result of the war are badly lighted in this respect. It is also necessary to look ahead and to plan a new building or extension with the possibility of further new buildings or extensions well in mind.

In a particular case which we have in mind a works was erected and amply provided with natural lighting facilities. The offices were situated in another part of the town, but the rapid growth of the business necessitated an office on the spot, and the only available site was such that the entrance of direct light to the works is now almost completely cut off, artificial lighting having to be relied upon almost entirely throughout the year.

The sky-line may be approximately determined by means of a series of overlapping photographs, or by measuring the distance from the point at which it is required to determine the illumination to the various obstructions, the heights of which are known.

In this way the percentage of clear sky may be ascertained, while it is also possible to determine the average angle of sky obstructions—an important factor in all daylight calculations.

RELATION OF WINDOW AREA TO FLOOR AREA.

In determining the window area for given areas of rooms certain ratios are frequently made use of for purposes of design.

It will be recalled that regulations are issued by the Board of Education and local authorities to this effect, and the various ratios may be stated as follows:

(1.) Ratio of window to floor area.
(2.) Ratio of window area to depth of room.
(3.) Ratio of window height to depth of room.

In (1) various ratios are given, 1 to 4 and 1 to 5 being American figures for factories, while 1 to 7 and 1 to 10 are specified for offices.

The ratio is, however, insufficient in itself, since it does not afford a true relative value of daylight facilities, the effect of obstructing building, etc.

The value may be of use, however, in comparing rooms and windows of similar character, arrangement, and exposure.

There is really no simple and ready means of estimating the necessary area and specifying the arrangements, or what is the minimum amount of daylight in which continuous work should be undertaken. The ratios just given fail, since they do not take the conditions into account, while the matter is further complicated in view of the varying intensities of daylight.

DAYLIGHT STANDARD CONSIDERATIONS.

The intensity requirements for daylight are higher than those for artificial light, because the physical condition of the eye during the daytime is usually such as to require a higher intensity of natural light for clear and easy vision than is required at night under ordinary well-designed artificial lighting systems. The ruling conditions must also be considered in fixing illumination values, and it is much more difficult to specify natural lighting requirements than the requirements for the same class of work under artificial lighting. The intensity required in the latter case may always be stated for every class of work with a certain degree of accuracy, but with natural lighting many conflicting elements make a definite prediction almost out of the question. It is much the safer plan to provide for adequate natural lighting under all conditions and to avoid anything but minimum specifications.

It is unfortunate that the extreme variability of daylight renders an actual measurement of the illumination at any particular spot of but little service as a standard. On the other hand, the ratio of the unrestricted illumination out of doors and the illumination at a certain point in a room should be an almost constant quantity dependent upon the nature of the building, but independent of climatic conditions within wide limits. Such a ratio might serve as a basis for rules for the attainment of adequate lighting.

The term "daylight factor" is used by the Departmental Committee on Lighting in Factories and Workshops, and defined by them as follows:

Daylight Factor.—" If it were possible to remove the walls and roof of a building and so allow the full amount of light from an unobstructed sky to reach a given point, the illumination there would have a very much enhanced value. The ratio of the actual value of the illumination to this enhanced value, expressed as a percentage, is termed the 'daylight factor,' and is a measure of the lighting efficiency of the building at the point under consideration. Compared with the variations of the outside illumination, the daylight factor may be regarded as roughly constant for any point in a factory, and mainly depends on the window area which is effective in admitting light to the point in question."

In connection with the natural lighting of schools, it has been suggested abroad that the illumination on the worst lighted desk should not be less than .5% of this so-called unrestricted illumination from a complete sky hemisphere. A similar conclusion has also been reached in this country.

It is perhaps more convenient to obtain what is known as the "sill ratio," or the ratio between the illumination at the worst-lighted spot and the illumination from a quadrant of sky received on a horizontal surface on the window sill. This value will obviously be affected by neighbouring obstructions, but the measurements so far taken indicate that a value of 1 to 100 should be the minimum ratio. This value is in substantial agreement with the one already given.

With such a ratio holding, artificial light would only be required towards the end of a winter's day.

Visibility depends upon contrasts in colour and shadow, and the absence of bright surroundings may cause a feeling of light shortage. Roof lighting without side windows and the presence of dirty walls produce this effect.

It is, therefore, difficult to state the actual value of daylight illumination that is adequate, the more so as a further factor—adaptation of the retina—affects the amount of daylight required.

With artificial lighting the illumination is fairly constant, and adaptation is not of prime importance, but, with natural light varying enormously in intensity, adaptation plays an important part.

The solution of the problem then seems to rest, not so much in the provision of any stated intensity, but in the adoption of a method which eliminates the question of variations in eye sensitiveness, and provides for a certain access of daylight to enable an adequate illumination with a certain brightness of sky to be obtained.

General Recommendations.

The causes of unsatisfactory natural illumination have been enquired into by the Departmental Committee, who state in their report: "While our enquiry has shown that there has been a general advance in matters of illumination, many instances of workrooms with poor natural lighting have been brought to our notice, both by personal inspection and by the evidence of witnesses. The reasons may be classified under a few headings, and it is worthy of remark that some of these may be remedied without much difficulty.

"1. *Old and Unsuitable Buildings.*—In striking contrast with most modern factories, which are usually excellently lighted, many instances have been noticed of unsuitable buildings, originally intended for dwelling-houses or for some other purpose, used as factories and workshops. In these the window area is generally deficient, and the windows are not carried up to the ceiling. Similar considerations often apply to old and out-of-date factory premises.

"Underground workrooms, again, are frequently poorly lighted, and in some instances are subject to the continuous use of artificial illuminants. No legislative restriction appears to be placed on the use of these premises for industrial purposes, however unsuitable they may be, with the single exception of underground bakehouses.

"2. *Obstruction of Light.*—Obstruction of light may be either external or internal.

"The former is generally due to the near presence of another building, and can be rectified to some extent if the obstructing surface be whitewashed or by the adoption of special reflectors and glass.

"Amongst the internal causes is the temporary storage of materials or finished articles near the windows, particularly in laterally lighted rooms in which bulky articles such as boxes are made or in which packing is done. In some cases much could be done to improve the lighting by storing the articles in such a way as to keep the windows as clear as possible. In top-lighted rooms obstruction may arise from high machines, and it is always present in weaving sheds containing Jacquard looms.

"3. *Dirty Windows.*—These are a very common cause of insufficient illumination. By many firms this is fully recognised, and arrangements are made for periodical cleaning.

"4. *Dirty Walls and Ceilings.*—These are frequently noticeable in foundries and other factories where the nature of the work involves the production of smoke or dust. Owing to the decrease in reflecting power, light is needlessly lost, and this effect is especially marked in factories lighted from saw-tooth roofs, where much of the light entering the windows is reflected from the sloping ceiling down on to the work.

"The effect of light-coloured walls and white ceilings on the general brightness of the room and in affording an effective background to dark objects is often overlooked, and we desire therefore to direct special attention to this means of increasing the illumination in workrooms at a minimum of expense.

"It will be seen that some of the causes mentioned above—namely (1) and to some extent (2)—which are especially noticeable in large towns where space is limited, cannot be entirely removed without very drastic measures. The remaining causes of unsatisfactory lighting, however, could be remedied without difficulty.

"If daylight is insufficient it can be supplemented by artificial light, although it has been suggested that a mixture of the two is less satisfactory than either alone. There is, however, the question of the hygienic importance of daylight as distinguished from artificial light. In some minor branches of industry—for instance, in the manufacture and use of photographic materials—daylight has to be excluded altogether, and in mining it is unobtainable. It is, however, not uncommon to find artificial light used continuously in workrooms to which these reasons do not apply, and the chief causes for this have been already stated. We have failed to obtain any definite evidence of direct injury to health resulting from such conditions, and, on the contrary, statistics have been produced tending to show that in one large factory the sickness rate was actually lower in a room in which artificial light is nearly always needed than in another room well supplied with daylight, in which similar work was carried on by persons of practically the same age and sex distribution. Nevertheless, we have found substantial consensus of opinion among witnesses of all classes that conditions involving the continuous use of artificial light are unnatural and entail greater strain on the workers. In this view we concur.

"The question is, however, very complex. Where there is external obstruction the amount of daylight diminishes (with equal window space) on each storey as we descend, and is therefore at a minimum in basement rooms. If the excavated area which such a room faces is so narrow as to reduce further the angle at which the sky is visible, there is additional interference with daylight illumination, just as there would be in a ground-floor room obstructed by a boundary wall of corresponding height and nearness; but if the area be wide, there is not necessarily much more difference, so far as adequacy of daylight is concerned, between the basement and the ground floor than between the ground floor and the first floor. There are, of course, other considerations, hardly within our province, to be taken into account with regard to basement rooms.

"It has to be remembered that a room originally well supplied with daylight may subsequently be darkened by conditions beyond the owner's or occupier's control—for instance, the erection of obstructive buildings opposite to it—and, further, that the distribution of daylight in different parts of a given room is dependent not only on the position in relation to the window, but also upon internal obstruction by machinery, etc.

"On the other hand, there are many devices by which additional daylight may be secured, and in overshadowed rooms the fullest use ought to be made of these, thus:

"(1.) The windows should be of adequate size and extend as near the ceiling as practicable.

"(2.) They should be kept clean and free from any unnecessary obstruction within.

"(3.) Vertical light can be deflected into the room by means of reflectors of prismatic glass.

"(4.) It may be possible to whiten the surface of an external wall or building which obstructs the light.

"(5.) The inside walls and ceiling should be white or nearly white.

"(6.) The positions of the permanent working points should be so adjusted in relation to the windows and to internal obstructions of whatever kind as to secure as far as practicable adequate daylight for each.

"It is obvious that the greater the fraction of outside light admitted, the later will artificial light be required in the evening, and the earlier will it be dispensed with in the morning."

CONCLUSION.

The aim of this work has been to show that both natural and artificial lighting are vital factors in our industrial and daily life, and we feel sure that anyone who takes the trouble to enquire even casually into the question must appreciate this fact.

The study of natural lighting has unfortunately been neglected in comparison with artificial lighting, but the former is by far the more important, since artificial is simply a supplement to natural lighting, and should be considered with it. A change must be made from one to the other at some period of the day, and it is but natural that all questions arising should be studied together. The eye, through the centuries, has developed under natural lighting, hence artificial lighting should be developed to suit the eye.

The requirements of artificial lighting are, therefore, essentially connected with daylight study, and the lighting engineer should be familiar with the daylight conditions on which the construction of the eye depends.

Man becomes efficient by induction and through association with efficient things. He degenerates under dirt and disorder, and inefficiency may be directly traced to association with inefficient men and things. Efficiency is largely habit, and in the majority of cases is merely a question of environment.

The absence of sufficient light is detrimental, in that dirt is allowed to accumulate unnoticed, and a workman quickly becomes slovenly amidst dirty surroundings.

Good lighting is also essential for proper supervision and for the detection and prevention of idling, whilst numerous cases are on record of injury caused to eyesight by glaring light sources and inadequate illumination.

The good light of a factory is one of its most valuable assets, for absence of light will render nugatory the best of efforts and intentions.

APPENDIX.

TABLE OF COSINES CUBED.

Angle.	Cosine.³	Angle.	Cosine.³	Angle.	Cosine.³
0°	1.	—	—	—	—
1°	0.999	27°	0.707	53°	0.218
2°	0.998	28°	0.688	54°	0.203
3°	0.997	29°	0.669	55°	0.189
	0.993	30°	0.649	56°	0.175
5°	0.988	31°	0.630	57°	0.161
6°	0.983	32°	0.610	58°	0.149
7°	0.978	33°	0.590	59°	0.137
8°	0.971	34°	0.570	60°	0.125
9°	0.963	35°	0.550	61°	0.114
10°	0.955	36°	0.529	62°	0.103
11°	0.945	37°	0.509	63°	0.0936
12°	0.935	38°	0.489	64°	0.0841
13°	0.925	39°	0.469	65°	0.0755
14°	0.913	40°	0.449	66°	0.0670
15°	0.901	41°	0.429	67°	0.0596
16°	0.888	42°	0.410	68°	0.0526
17°	0.874	43°	0.391	69°	0.0460
18°	0.860	44°	0.372	70°	0.0400
19°	0.845	45°	0.353	71°	0.0345
20°	0.829	46°	0.335	72°	0.0295
21°	0.813	47°	0.317	73°	0.0250
22°	0.797	48°	0.299	74°	0.0210
23°	0.780	49°	0.282	75°	0.0173
24°	0.762	50°	0.265	76°	0.0142
25°	0.744	51°	0.249	77°	0.0114
26°	0.726	52°	0.233	78°	0.0090

NATIONAL INSTITUTE OF INDUSTRIAL PSYCHOLOGY

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